



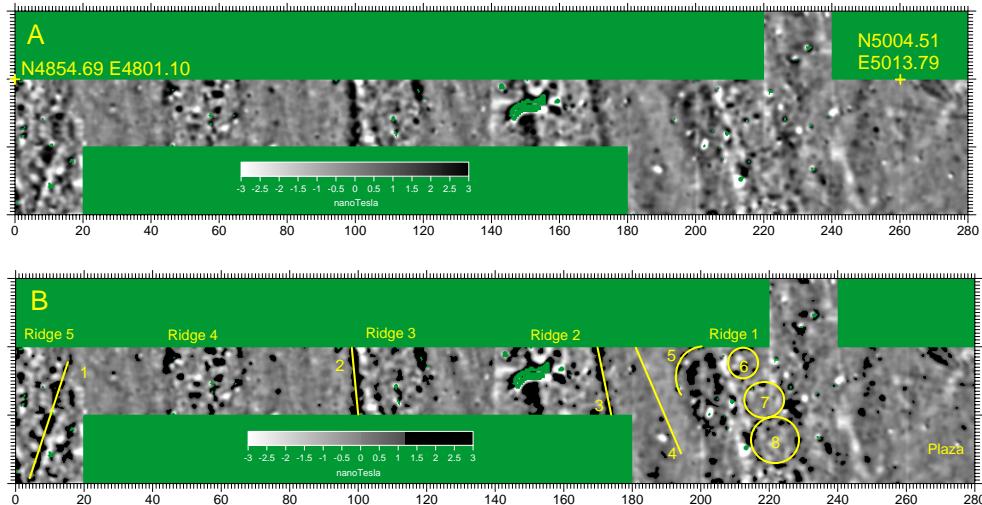
**US Army Corps  
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Engineer Research and  
Development Center

# Geophysical Archeological Survey at Poverty Point State Historic Site (16WC5) West Carroll Parish, Louisiana

September 2002

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**and**

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## ABSTRACT

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A near-surface geophysical survey was conducted at three locations—portions of Mound E, West Sector, and Southwest Sector—at the Poverty Point site (16WC5), Louisiana, during 21-22 June 2001. Technologies employed included: magnetic field gradiometry, electrical resistivity, electro-magnetic in-phase/conductivity and ground penetrating radar. The gradiometer and resistivity results clearly indicate that these two geophysical approaches have the potential to greatly enhance research strategies and guide data recovery efforts within specific locations at the site. Problems in the manner in which certain resistivity datasets were collected and/or processed prevent their use in interpretations for all areas surveyed. The conductivity results generally reflect the topography of the surface expression of the site but did not yield the detailed data that were anticipated. Additional resistivity and conductivity surveys are needed to address the user/equipment problems encountered in this study. The ground penetrating radar results were inconclusive due to the high proportion of clay particles in the loess sediments and it is recommended that this technology not be applied to the site until further refinements are made to this technology to address the unique site-specific conditions.

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## CHAPTER I: INTRODUCTION

Having the ability to locate and characterize potential archeological feature types across the Poverty Point site would improve research capabilities immensely. One method that shows promise in facilitating this goal is the application of geophysical survey. The purpose of this report is to demonstrate efforts to test, explain, and interpret geophysical data collection and processing procedures, and make recommendations for testing the reliability of the results.

The authors conducted a series of geophysical surveys at three locations within the Poverty Point State Historic Site (16WC6), 21-22 June 2001. A permit for this work was issued 11 June 2001 by the Louisiana Division of Archaeology for non-intrusive archeological research on Louisiana State cultural resources. The intent was to test four different geophysical techniques and determine which instruments work best at detecting subsurface anomalies that are indicative of cultural features, where, and under which circumstances. The instruments/techniques tested were: ground penetrating radar (GPR), electro-magnetic (EM) conductivity, electrical resistivity, and magnetic field gradiometry. The authors were assisted by a team of anthropology graduate students, under the direction of Jay K. Johnson, from the University of Mississippi.

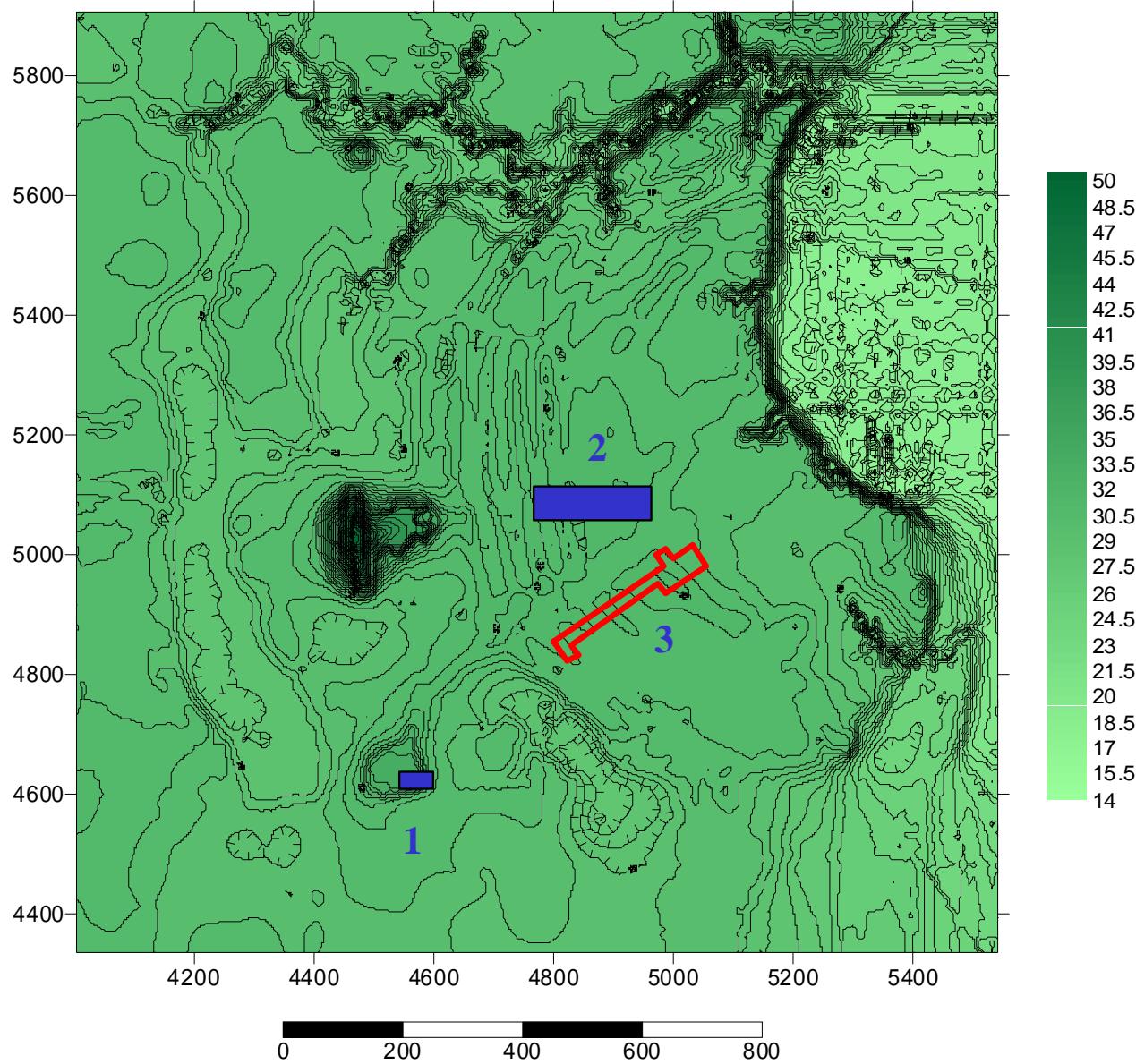
Three areas were investigated (Figure 1):

1. The southern portion of the platform atop Mound E.
2. The ridges/causeway/plaza area of the West Sector, east of Mound A.
3. Ridges 1-5 and east edge of the Plaza in the Southwest Sector.

This report discusses the various geophysical technologies, their applications and limitations, and offers guidance regarding the uses of these methods as a tool to aid future research at Poverty Point.

### *SETTING AND SIGNIFICANCE*

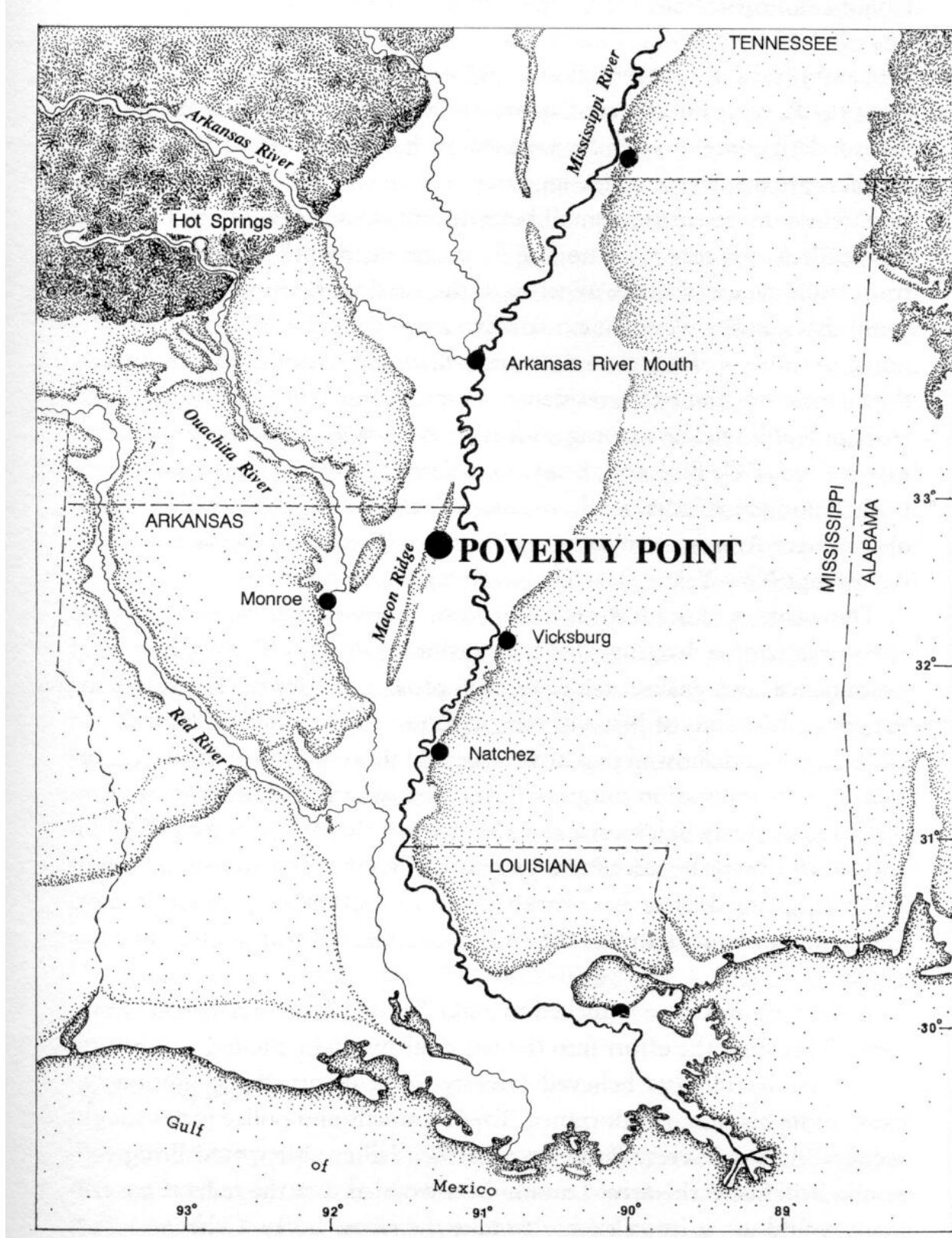
The Poverty Point site, located in rural West Carroll Parish, Louisiana, is situated on Macon Ridge, a remnant Pleistocene terrace along Bayou Macon and overlooking the ancient Mississippi River floodplain (Figure 2). This setting provided a conducive environment for the inhabitants and facilitated the development of a distinctive culture that influenced contemporary cultures throughout the eastern half of North America. It is one of the most important Late Archaic archeological sites in North America (Kidder 2000). The site is so important that it is recognized as a National Historic Landmark, characterized by its immense and well-ordered monumental architecture—six semi-concentric rings and five mounds (Saunders et al. 2001)—and its unique and varied material culture. The climax for the site construction and culture evolution is framed between 1,730 and 1,350 B.C. (Gibson 2000).



**Figure 1. Poverty Point Map, Areas of Investigation**

- 1. Mound E**
- 2. West Sector, East of Mound A**
- 3. Ridges 1-5, Southwest Sector**

*Map data supplied by Louisiana's Ancient Mounds and Heritage Area Trails Advisory Commission, Louisiana Division of Archaeology (2000).*



**Figure 2. Poverty Point, Location and Setting (reprinted with permission from the University Press of Florida)**

As T.R. Kidder (2000) points out, “Poverty Point is critical because it represents an early example of social and political complexity in North America. Indeed, the site is seen by some as a textbook case for the evolution of a non-agricultural, socially complex, culture (Bense 1994; Fiedel 1992)”

Although it has been the focus of repeated interest by archaeologists throughout the 20<sup>th</sup> Century, much of the current understanding of the site evolution, subsistence, lifeways, and social order remain speculative and largely based on data recovered from surface finds and limited test excavations (cf. Connolly 2001; Ford 1955; Ford and Webb 1956; Gibson 1980, 1987, 1989, 1994a, 1994b, 2000; Haag and Webb 1953; Jackson 1991; and Webb 1968, 1977).

One important recent contribution in Poverty Point research that has facilitated this study is the release of the digital topographic data used to produce the maps depicted in Figures 1 and 13. The data was collected and processed by T.R. Kidder and a team from Tulane University for the Louisiana Ancient Mounds and Heritage Area Trails Advisory Commission, Louisiana Division of Archeology (2000). This dataset is referenced to all preexisting datums across the site and marks a pivotal point in Poverty Point research because it was produced to address the needs and concerns of archeologists. The digital format of the map data lends itself easily to a wide variety of analysis and multiple scales and should prove to be a valuable resource for all future research.

## CHAPTER II: PREVIOUS RESEARCH

### *PREVIOUS GEOPHYSICAL RESEARCH AT POVERTY POINT*

This report represents the third application of near-surface geophysical techniques at Poverty Point. The first geophysical survey is attributed to Keller (1981), who conducted a resistivity survey atop Mound D (Sarah's Mound). His focus was on the much more recent use of Sarah's Mound as a burial ground for the early Euro-American settlers, specifically to the 19<sup>th</sup> Century graves scattered across the top of the mound. He concluded that the standing historic grave markers did not correlate to the suspected grave shafts he detected. That is, either the markers had been either moved or displaced over time, or, possibly never placed correctly due to the time lag from burial to the manufacture and delivery of the grave marker to the site, which minimally would have taken several months during that period.

More recently, in support of Gibson's 1988 excavation at the "Dock," James Doolittle, (1989) conducted a geophysical study to determine the usefulness of GPR at Poverty Point (Gibson 1989). Doolittle employed a SIR System with 120 and 500 MHz antennas. He conducted GPR survey of five transects: a North/South transect 575 m long; an East/West transect 400 m long; and three undesignated auxiliary transects, two 200 m, and one 300 m in length (Mayer 1989: Figure D-1). Doolittle concluded that while the technology could not be used effectively to discriminate buried cultural features it did prove useful in identifying areas with subsurface disturbances (e.g., pipe trenches). He concluded that the failure to identify cultural phenomena was due to their dispersed distribution and low reflection coefficients (Mayer 1989).

Since these initial field trials of the two technologies in the 1980's, tremendous advances in information technologies have occurred. These advances have been incorporated into the Geoscan geophysical instruments, which have allowed the instruments to be applied in a more useful manner to support and focus archeological research objectives.

## CHAPTER III: GEOPHYSICS AND ARCHEOLOGY

*Somers and Hargrave (2001) have been condensed here to better explain briefly, the history, relevance and methodological applications of multi-instrument geophysical surveying to archeological investigations.*

Geophysics is that branch of the earth sciences dealing with physical processes and phenomena in the earth. Archaeologists have used geophysical techniques for more than 50 years (Heimler and DeVore 1995:1). A number of overviews of geophysical techniques relevant to archeology are available (cf., Clark 1990; David 1995; Ebert 1984; Gaffney et al. 1991; Heimler and DeVore 1995; Weymouth 1986; and Wynn 1986), and no attempt will be made to reiterate these here (Somers and Hargrave 2001).

Geophysics is much better integrated into archeological research in Great Britain and Europe than in North America. In the Old World, many archeological sites include substantial architectural remains and abundant metal artifacts. These materials were relatively easily detectable by early geophysical instruments, and this contributed to the early acceptance of geophysics by Old World archaeologists. In contrast, North American sites tend to be much more ephemeral. Prehistoric architectural remains and other features are generally manifested in the archeological record by relatively subtle differences in soil color and texture. Stone architecture does not occur in many regions, and metal artifacts are, for all practical purposes, absent at prehistoric sites. The low contrast between cultural deposits and the surrounding matrix results in a relatively weak response to geophysical survey methods. Also contributing to the weak response is the relatively small size of the cultural features (pits, postholes, and hearths) characteristic of most North American prehistoric sites. At historic sites the contrast may be much greater and architectural features tend to be much larger. Thus, survey design for historic sites is less critical than for prehistoric sites (Somers 1997).

### ***RESEARCH DESIGN***

#### **Methods**

Geophysical methods used at the Poverty Point site included electrical resistivity, magnetic field gradiometry, electro-magnetic (EM) conductivity, and ground penetrating radar (GPR) (Figure 3). The collective benefits of multiple instrument geophysical survey are that:

- Multiple methods can identify which instruments are best suited for specific site conditions;
- They can detect a wider range of feature types;
- They can provide more information on feature characteristics.

Survey conditions were ideal with the exception of a late afternoon thundershower on the evening of 21 June 2001. Grass had been recently mowed and there were relatively few obstructions (e.g., metal structures, trees, pavement) that interfered with the data collection efforts (Figure 4).



**Figure 3.** Resistivity (top left), Ground Penetrating Radar (top right) and Fluxgate Gradiometer (bottom)



**Figure 4.** General surveying conditions, 21-22 June 2001 (gradiometer [left], ground penetrating radar [right], view facing east)

## **Total Station**

UTM coordinates for georeferencing the survey grids were collected and provided by Jay K. Johnson and John Peukert from the University of Mississippi. The survey team referenced the permanent monuments/datums established by Jon L. Gibson. The coordinates referenced in this study correspond to the system used for the Poverty Point Mapping project conducted by T.R. Kidder, et al., for the Louisiana Ancient Mounds and Heritage Area Trails Advisory Commission, Louisiana Division of Archaeology (2000).

While the coordinates established for the multi-instrument area of investigation on Ridges 1-5, Southwest Sector, are valid and reliable (based on triangulation between monuments 1, 2, and 5), there were errors in collecting the coordinates for the grids that were surveyed at Mound E and in the West Sector, east of Mound A. Based on discussions with Johnson and Peukert, it appears that an error was entered into the record during station changes and these errors became evident when the map was produced subsequent to the field work by the authors. The coordinates for these two areas are approximate and do not represent the actual configuration and alignment of the grids that were actually surveyed. Therefore, to recognize this error, these two areas are depicted as generalized blue coverages in Figure 1. At this time it is not possible to correct these errors. The geophysical data collected from these areas do contain useful information and have been included in the discussion in Chapter IV: Results and Recommendations.

## **Survey Design**

Although a number of archeological excavations have been conducted at the site over the past 100 years, they have not provided a clear understanding of the nature, distribution, and density of archeological features such as pits, hearths, postholes, and other structural remains. Given this lack of baseline information, it was decided to adopt a conservative survey design. Fieldwork emphasized high data density (i.e., a relatively large number of data points per square meter) rather than an attempt to maximize the area covered. The intention was to collect data in a manner that would permit the detection of relatively small, very low contrast subsurface features. The methods used to collect and process data in the resistivity and gradiometer surveys conformed to widely used procedures developed by Geoscan Research (USA and UK).

- 20 x 20 m grids laid out using non-magnetic tapes and oriented west-east.
- Data points per square meter varied among instruments.
- The gradiometer survey was based on 16 points per square meter.
- The resistance survey was based on 4 points per square meter (i.e., two probes spaced at 0.5 meter with readings taken every 0.5 m).

## **Electrical Resistivity**

Electrical resistivity surveys (Bevan 1998; Heimler and DeVore 1995; Scollar et al. 1990) introduce an electrical current into the ground and measure the ease or difficulty with which the current flows through the soil. The unit of measure is the ohm. Resistivity is governed by the number and mobility of free charge carriers (principally soluble ions). The simultaneous availability of soil moisture and soluble salts determines the free charge carrier concentration in the soil. The mobility of the soluble ions is governed by soil moisture content, soil grain size, temperature, soil compaction, and the surface chemistry of the soil grains. Archeological features often have resistivity properties that differ from

the surrounding soils. It is this contrast that creates the signal of interest in an electrical resistivity survey (Somers and Hargrave 2001; Somers 1997:23).

The electrical resistivity method is characterized by several potential disadvantages. The method is not suitable for situations where the soil is water saturated. Use of a resistivity instrument involves insertion of probes into the ground at each point where data are collected, with the result that the rate at which an area can be surveyed is slower than that achieved in magnetic (e.g., gradiometer) surveys. Also, like the other geophysical techniques, resistivity may not detect very small and/or low contrast targets.

The resistivity survey was conducted using a Geoscan Research RM-15 Resistance Meter equipped with an MPX15 Multiplexer and PA5 probe array. The transects were spaced 1 m apart in the east-west direction. The recorded data consisted of (1) the resistance value; (2) the grid number; (3) the transect line number; and (4) the line position. Data were collected at 0.5-m intervals along the west-east transects, and transects were spaced at 1-m intervals north-south. The data sample density was four samples per  $\text{m}^2$ . The frequency, current value, and integration time were adjusted to ensure that random defects in the survey associated with the instrument would be less than 1:1000.

## Gradiometer

Magnetic field gradient surveys (Bevan 1998; Heimmer and DeVore 1995; Scollar et al. 1990) can be thought of as mapping deviations from uniformity in the earth's magnetic field that are caused by the presence of archeological features and/or artifacts. The earth's magnetic field changes continuously through time and short-term changes are usually greater than the distortion associated with archeological features. Temporal change must be removed from the survey data to reveal distortions associated with archeological phenomena. Therefore, archaeomagnetic surveys are ideally performed with two magnetic sensors (magnetometers). One magnetometer is used to record the time-variable component, and the other records the spatial data and time-variable component. The later component is removed from the survey data by subtraction. The Geoscan FM-36 used in this study includes two fluxgate sensors. Magnetic data are measured in nanoTeslas (nT, i.e., one billionth of one Tesla; Somers and Hargrave 2001; Somers 1997:23–24).

The archeological record has two basic properties or mechanisms that distort the earth's magnetic field: remnant magnetization and magnetic susceptibility. Remnant magnetization is the familiar “permanent magnet” effect and is associated with iron and steel objects, ceramics, hearths, fire pits, and some fire-altered rocks and soils. In these materials, the remnant magnetization originates from heating iron oxides (found in most but not all soils) above a critical temperature (565–675° Centigrade). When the soil cools, the temperature induced changes in the iron oxide crystals become permanent. It is this change that generates a remnant magnetic field. This thermally created magnetic field adds vectorially to the earth's magnetic field to cause a local distortion. Thus, most cultural objects and processes associated with heating are potential archaeomagnetic survey objects of interest (Somers and Hargrave 2001; Somers 1997:23–24).

Magnetic susceptibility alters the earth's magnetic field directly in a manner roughly analogous to the way porosity alters the flow of water through a solid. Where magnetic susceptibility is large (high porosity) the magnetic field is increased, and where the magnetic susceptibility is low (low porosity) the magnetic field is decreased. Many cultural objects and processes (thermal, biochemical, physical, and mechanical) locally increase the magnetic susceptibility of the native soil. The mechanism for this increase also is associated with changes in the iron oxide crystal structures within the soils. Local

changes in site magnetic susceptibility alter the earth's magnetic field, and it is this distortion that can be mapped. In magnetic surveys, remnant magnetization effects are usually somewhat greater than susceptibility effects (Somers and Hargrave 2001; Somers 1997:23–24).

The magnetic survey was performed with an FM-36 Magnetic Gradiometer, manufactured by Geoscan Research (UK), a small British firm specializing in geophysical instruments optimized for archeological application. This instrument contains two magnetometers separated vertically by 0.5 m. In operation, this instrument records: (1) the magnetic field distortion as the difference in the data from the two magnetometers; (2) the grid number; (3) the traverse line number; and (4) the line position. By recording the data difference between the two magnetometers this instrument also removes the time variable components associated with the earth's magnetic field—diurnal fluctuation. The survey grids were scanned with the FM-36 in a raster format. The survey was conducted from west to east along a traverse, followed by a second scan along the adjacent traverse (0.5 or 1 m south of the first) from west to east. This sequence was repeated until the entire grid was surveyed.

The FM-36 Magnetic Gradiometer was operated on the 0.1 nT sensitivity range. Data sample density in the Southwest Sector survey area was 16 samples per m<sup>2</sup>. Eight readings per meter were collected along the west–east transects, and transects were spaced at 0.5-m intervals north–south. Considerable care was taken to balance and align the instrument properly before each grid was surveyed. The site was relatively quiet magnetically, and proper configuration of the instrument was not difficult to achieve.

### **Electro-Magnetic Conductivity**

The electro-magnetic (EM) induction method is commonly used to measure apparent ground conductivity. The conductivity of a material is dependent on the degree of water saturation, types of ions in solution, porosity, chemical constituents of the soil, and the physical nature of the soil. Due to these factors, conductivity values can range over several orders of magnitude.

There are two components of the induced magnetic field measured by the EM equipment. The first is the quadrature phase component, sometimes referred to as the out-of-phase or imaginary component, which gives the ground conductivity measurement. Disturbances in the subsurface caused by compaction, soil removal and fill activities, or buried objects may produce conductivity readings different from that of the background values, thus indicating anomalous areas. Electrical conductivity is a positive valued parameter. However, due to the design of the instrument used in this survey to collect conductivity data, it is possible to obtain a negative value when the instrument passes over a metallic object. Although a negative conductivity value is physically meaningless, it does aid in the detection of metallic material. Quadrature readings are reported as milliSiemen/meter (mS/m). The second component is the inphase or real component, which is the ratio of the induced secondary magnetic field to the primary magnetic field. The inphase component is primarily used for calibration purposes; however, it is also sensitive to metallic objects. The inphase component is measured relative to an arbitrarily set level and assigned units of parts per thousand (ppt). Since it has an arbitrary reference level, the reading can be either a positive or negative value.

A Geonics EM38BB terrain conductivity meter was used for this investigation. The EM38BB operates in the frequency domain at 14.6 kHz, has a transmitter-receiver coil separation of 1 m, and a maximum effective depth of investigation of approximately 1.5 m. The instrument can be operated in both a horizontal and vertical dipole orientation, each having different depths of investigation. The instrument is normally operated with the dipoles vertically oriented (coils oriented horizontally and co-

planar), which gives the maximum depth of penetration. For this survey the EM38BB was operated in the vertical dipole mode to achieve the maximum depth of investigation.

The EM38BB data were collected using a 0.6-second sampling interval as the operator walked along profile lines spaced 0.5 m apart. At this pace, the data were acquired at about 3 measurements per meter. Measurements were taken at the ground surface and a fiducial mark placed in the data file at 10 m (mid-grid) to provide distance control.

## Ground Penetrating Radar

Ground penetrating radar (GPR) is also an electro-magnetic method, however it differs significantly from the induction EM method described above and warrants a separate discussion. At the lower frequencies (kilohertz range) where EM induction instruments operate, conduction currents (currents that flow via electrons in a metallic matrix or ions in solution) dominate and energy diffuses into the ground. At the higher frequencies (megahertz range), which GPR utilizes, displacement currents (currents associated with charges that are constrained from moving any distance) dominate and EM energy propagates into the ground as a wave.

GPR is used to image the subsurface by transmitting an electromagnetic pulse into the earth and measuring the return signal. The frequencies employed in GPR typically range from 10 to 1000 MHz. While in the earth, the EM signal undergoes refraction, reflection, scattering, and dispersion. Contrast in the dielectric permittivity at material boundaries causes the electro-magnetic wave to be reflected and refracted. Soil conductivity is a major factor in determining if GPR can be used successfully at a site. High conductivity soils, such as those with a high clay and moisture content, can significantly attenuate the EM signal and frequently render GPR virtually useless.

Ground penetrating radar instruments include an antenna, which contacts the ground surface and sends and receives a low frequency electromagnetic signal into the earth. The reflected signal is then compared to the original input. The manner in which the signal is reflected or attenuated, as well as its magnitude or amplitude, phase (negative or positive), and frequency provides information about the nature of the subsurface materials. Radar can provide cross-sectional maps that are informative about soil strata, bedrock, buried objects, and cavities or voids (including cultural features). Current radar instruments and supporting software allow the operator to view survey results on a computer screen as the survey is underway.

A Sensors & Software, Inc. Noggin system was used to collect the GPR data. The Noggin is noted for its user-friendliness, simplicity, and self-contained data acquisition system. Both the transmitter and receiver antennas are contained in one unit mounted on a cart that is pushed along the surface at a slow walking speed. The GPR survey was performed in reflection mode with the antennas oriented perpendicular to the survey line. In reflection profiling, the transmitter and receiver antennas are kept a fixed distance apart and both antennas are simultaneously moved along the survey line. A wheel odometer attached to the system is used to monitor distance traveled and initiate data sampling at 5-cm increments. The time (in nanoseconds) required for the EM wave to travel through the subsurface and return to the receiver is recorded at each sample station.

The GPR profile is constructed by plotting the received signal against two-way travel time at each sample station along the survey line. A 1000 MHz antenna was initially used on 21 June 2001 to begin the Southwest Sector survey in hopes of acquiring high-resolution near-surface images. However, the local soil conditions did not allow sufficient penetration of the signal (about 25 cm) so a 250 MHz

antenna was used to complete this phase of the survey. The GPR profiles were also conducted along survey lines spaced 0.5 m apart.

## **Data Processing**

All resistivity and gradiometer survey data were processed using Geoplot 3.0 software. This software is provided by the instrument manufacturer and is optimized for the data characteristics and processing objectives associated with archeological survey. This software allows georeferencing of anomalies and potential features for ground truthing. Geoplot has processing capabilities that allow different contrasts and views of datasets to be presented graphically as well as allowing statistical analysis. The processed data were exported into Surfer 7.0 to produce the image maps presented here. The maps viewed in Geoplot and/or Surfer on the computer screen are significantly crisper than those presented here.

The processing objective for the resistivity data was to detect and map small, potentially low-contrast features (e.g., pits) that are slightly higher or lower in resistivity than the surrounding soil. De-spiking the data and performing a highpass filter operation with the Geoplot software refined the data so that the resultant images were more interpretable. The de-spiking routine in Geoplot removes outlier data values. Highpass filtering enhances the visibility of small, low-contrast features. The highpass filtered map has a mean value of zero. Approximately one-half the filtered data are positive (resistivity value greater than the local background) and one-half are negative (less than the local background). Positive and negative resistivity anomalies may represent potential archeological features, depending on size, magnitude, configuration, and orientation, and represent targets for future archeological investigation.

Several problems complicated the processing of the resistivity data. As noted, grids were collected using two different probe configurations. To date, hardware problems with the MPX multiplexer have prevented us from merging the two datasets that result from use of the parallel twin (side-by-side) configuration. An additional problem resulted from a heavy rainfall while Grid 3 was being surveyed. The abrupt increase in soil moisture resulted in rather sharp differences in the mean values for various grids, and these differences are apparent at the grid intersections. These problems could not be corrected for integration into this report. To address this problem a resistivity survey is planned to resurvey Grids 1-4 and reevaluate the datasets. Ideally, the results will offer further insight and corroborate the findings presented below.

The processing objective for the gradiometer data was to detect small, very low contrast features. This was achieved by first removing survey bias defects, interpolating the data to achieve symmetrical pixels, and then applying a 1-m-diameter Gaussian weighted lowpass filter. The resultant map has a mean value of zero. Approximately one-half the filtered data are positive (corresponding to a local increase in magnetic field strength) and one-half are negative (corresponding to a local decrease in magnetic field strength). The statistical averaging associated with the lowpass filter also had the effect of further reducing the noise level (standard deviation) in the magnetic map.

The data processing for the electro-magnetic conductivity and ground penetrating radar are discussed in Appendix B.

## CHAPTER IV: RESULTS AND RECOMMENDATIONS

A multi-instrument geophysical survey was conducted at the Poverty Point State Historic Site (16WC5), Louisiana, during 21-22 June 2001. A total of 13,600 m<sup>2</sup> were surveyed (gradiometer-13,600 m<sup>2</sup>, resistivity-2,800 m<sup>2</sup>, EM-1,600 m<sup>2</sup>, and GPR-400 m<sup>2</sup>). The three areas we examined were (see Figure 1):

1. The southern portion of Mound E.
2. The ridges/plaza/causeway area of the West Sector, east of Mound A.
3. A transect bisecting Ridges 1-5, and interface of the adjacent plaza, of the Southwest sector.

The magnetometry and, to a lesser degree, resistivity results clearly indicate that these two geophysical approaches have the potential to greatly enhance research strategies and guide data recovery efforts at specific locations within the Poverty Point site.

### *MOUND E*

The intent was to survey three grids atop Mound E, or Ball Court Mound, to see if we could identify anomalies that would be suggestive of cultural features in order to facilitate ongoing research being conducted by T.R. Kidder and Tony Ortman, of Tulane University.

The datasets from the gradiometry instrument reveal no discernable features besides the parallel features that correlate to the modern field road and recent metal artifacts (Figure 5). In Figure 5, the green areas indicate where outlier values have been deleted. These values can be attributed to a metal fence post, a metal pin flag and other metallic debris scattered across the surface. It should be noted that the area surveyed here lies immediately below an electrical power transmission line and the area surveyed was within the right-of-way (ROW) of the power line. Impacts that could be noted in the datasets included the field road tracks as well as metal objects embedded atop the mound.

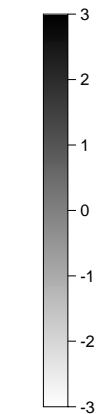
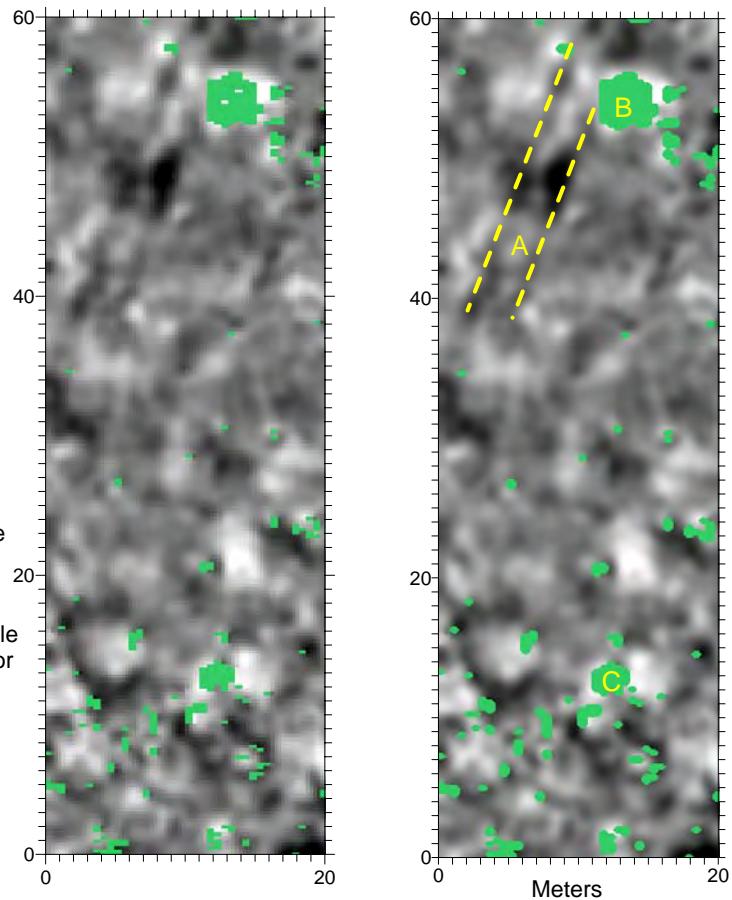
The same area was subjected to a resistivity survey with the probes configured into a parallel twin array with probes spaced at 0.5 meters. Because of the user/equipment problems discussed above and below, those datasets are not useful and no conclusions could be inferred from the datasets here.

## Poverty Point Mound E Magnetic Field Gradient Survey

Data collected by  
University of Mississippi

Note: Green indicates where  
strong positive or negative  
values have been deleted.

Grid coordinates not available  
for this area. See Figure 1 for  
general location.



nanoTesla

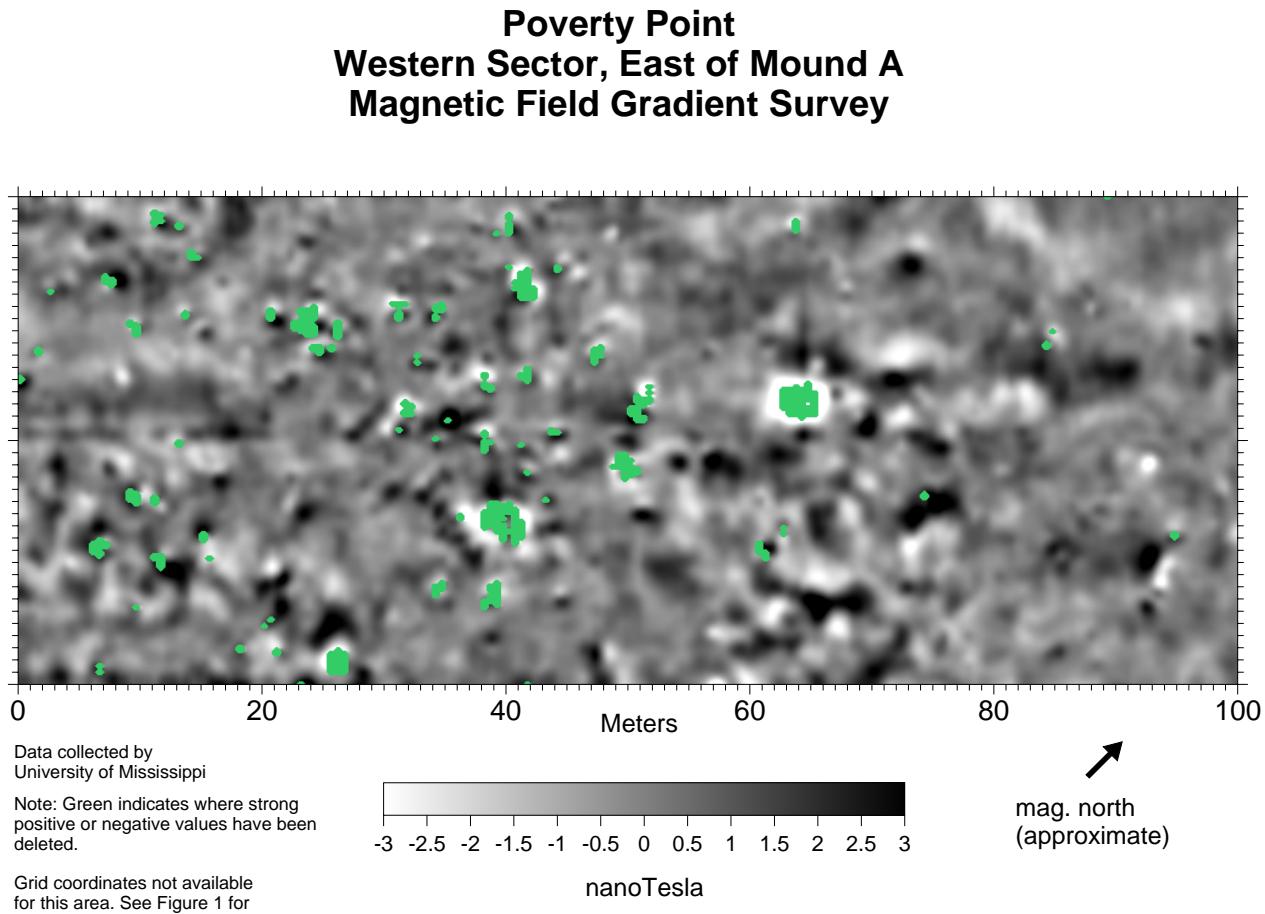
Key:  
A = Vehicle tracks  
B = Metal post  
C = Pin flag

↗  
mag. north  
(approximate)

**Figure 5. Gradiometer Image Map of Mound E (Ball Court Mound)**

## GRADIOMETER DATA FROM THE WESTERN SECTOR

The University of Mississippi team expressed interest in investigating this area to determine whether the central causeway, which reportedly bisected the ridges in this area, could be detected. They surveyed a 40 by 100 meter block (see Figure 1) and produced the image shown in Figure 6. While the causeway and ridges aren't visible in this image, the undetectability of these features may be attributed to the complex nature of the deposits in this area. Notice the entire survey area is composed of large, amorphous shaped, magnetic anomalies interspersed with magnetically quieter areas.



**Figure 6. Gradiometer Data from the Western Sector**

Glen Greene conducted systematic soil coring in this area in 1992 (Connolly 2001). Although a report has yet to be submitted detailing his findings, the results, as conveyed to us (personal communication, Dennis LaBatt, 22 June 2001), are that the entire area in this portion of the site is composed of a heterogeneous mix of midden and sterile fill material that may be up to several meters deep. That is, the ridges and swales were built using the same mixed soil materials over a very large area of the site, and on top of the underlying landform. This remains to be proven. However, if this is true, and the gradiometer data does reflect a wide variability in the readings, then this could explain why they were unable to detect patterns in the data that would correspond with the ridge and swale topography. What is troubling though, is the large size of the anomalies. Many are several meters across and amorphous

in shape. Was there an intentional effort that called for mixing sediments in the construction process, or is it just random patterning?

Gibson (2000) offers one explanation that may account for these results. Elsewhere on the site he noted that Crowley's clay, exposed along Bayou Macon was consistently mined and used as a construction and/or fill material across the site. If that occurred here, then that would explain the magnetic variability of the sediments—a heterogeneous mix of clay and loess sediments.

Even if the entire landform were manually constructed in this area, one would expect to detect some magnetic differences between ridges and swales in terms of distribution of features and artifacts. Perhaps construction occurred in a series of punctuated episodes rather than incrementally (as in gradual midden formation). Another plausible explanation is that modern modification, via agricultural practices, could have led to truncation and lateral spreading of the prehistoric deposits. This might explain why the ridges/swales are not discernable in the datasets.

Regardless, the results of the University of Mississippi survey do yield preliminary information on the use of geophysics in this portion of the site and provide an important and valuable lesson learned regarding intrasite variability of the deposits at Poverty Point. The nature, extent, and signature of the deposits from the this area, when compared with the other areas examined, indicate considerable intrasite variability and suggest that different soils with specific mechanical properties were intentionally used. Ground truthing via soil coring and large-scale excavation units/trenching could prove or disprove this interpretation.

### *RIDGES 1-5, SOUTHWEST SECTOR*

No recorded archeological excavations had been conducted in the area examined in this segment of the study. Ideally, we wanted to survey areas that likely contained discrete archeological deposits, which would allow the instruments to differentiate the cultural features from the surrounding matrix. Ridges 1-5 of the Southwest Sector have a low frequency of magnetically detectable artifacts—Poverty Point objects (PPOs)—and the occurrence of domestic/architectural features. The reference for this decision is Webb's (1982) artifact distribution pattern interpretation (Figure 7) and recommendations by Robert Connolly, Station Archeologist.

Webb's interpretations, based largely on surface finds, indicate that microflint blade artifacts are by far the predominant material culture that best characterize the Southwest Sector. These blade tools indicate a very specialized production/use function that is localized, and are distributed in distinct patterns geographically, by sector at Poverty Point. Although the chert material is not magnetic, other human activities associated with these locales may have left organically enriched areas, which should be detected geophysically.

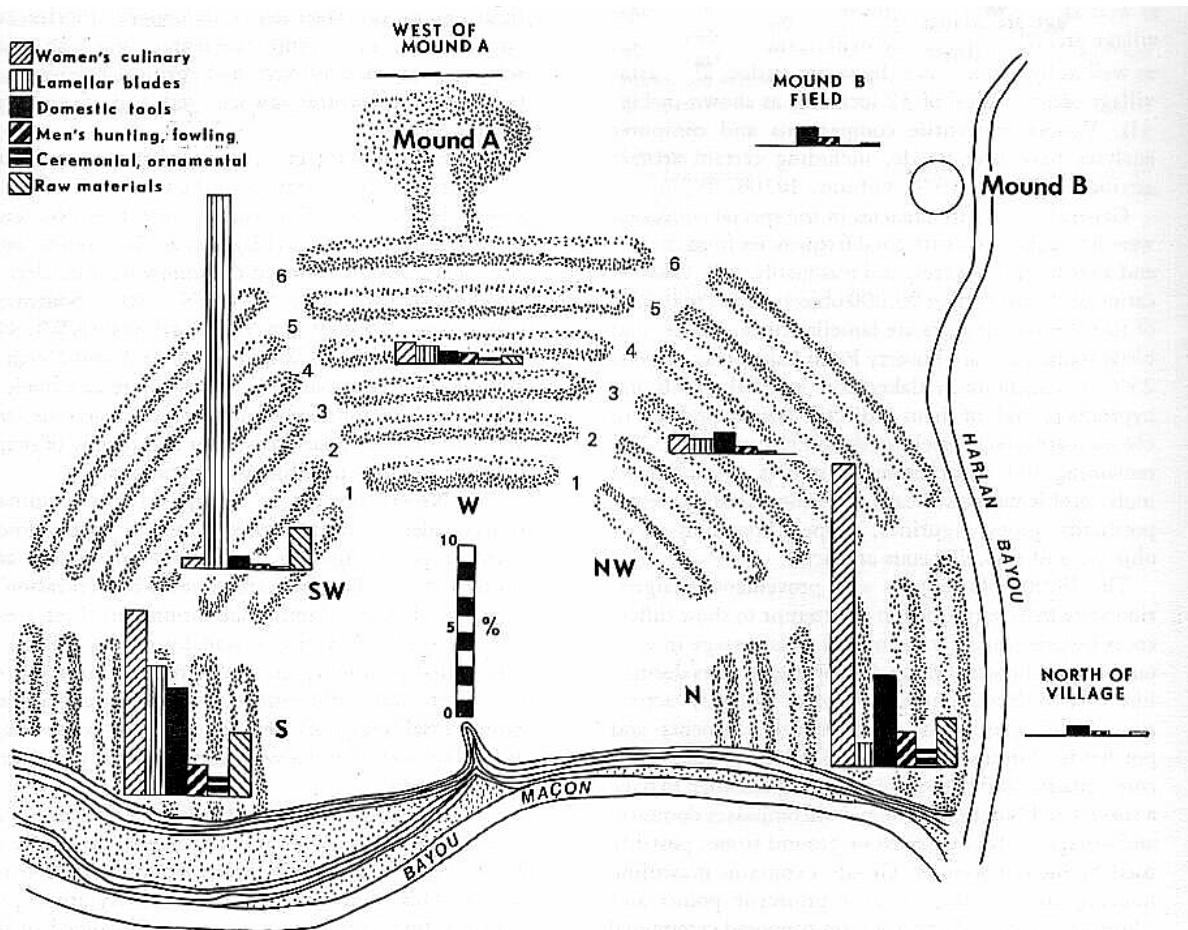


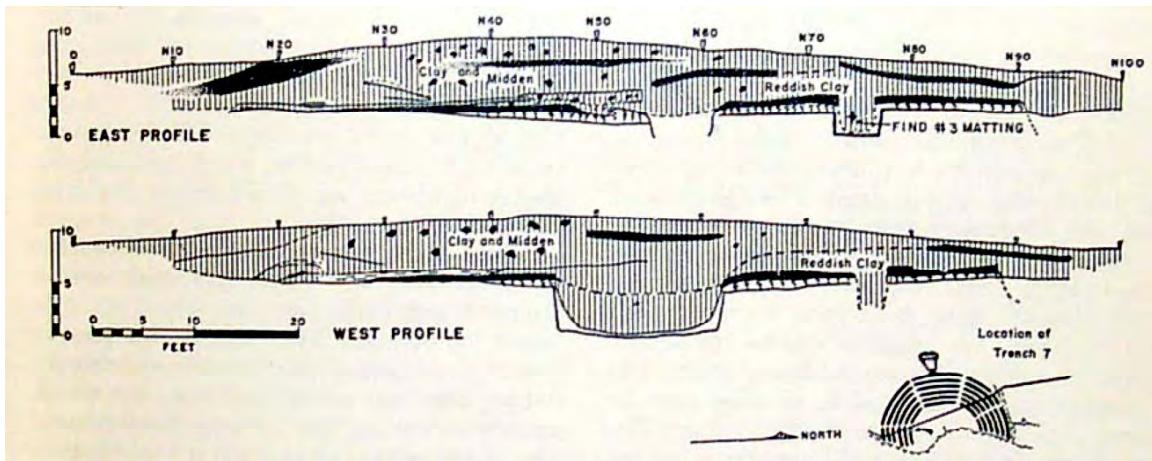
FIGURE 31. Percentage distribution of artifacts in the various sectors and adjoining areas at Poverty Point site. Classes of artifacts are grouped by presumed gender or social class usage and expressed in percentage of total collection (18,727 objects).

### Figure 7. Intrasite Artifact Distribution and Variability Map (Webb 1982)\*

The profiles in Figure 9 and others from across the site were reviewed in order to interpret and extrapolate what types of sediments and archeological deposits we might be detecting (Ford and Webb 1956). This profile depicts accretional deposits and midden attributed to episodal construction and use of the ridges through time. It should be noted that Ridge 1 in the Southwest Sector is the best preserved of the ridges in that portion of the site.

All four geophysical technologies were tested. The results, while varying noticeably between instruments, provided useful information. The gradiometer and resistivity datasets compliment each other, and to a lesser degree, so does the conductivity data. This study has demonstrated the potential benefits of a multi-instrument approach. The survey areas and the grid coordinates are depicted in Appendix A.

\* Reprinted with permission from Clarence H. Webb, The Poverty Point Culture, p. 66, *Geoscience and Man* 17 (1982), 2<sup>nd</sup> Edition. Geoscience Publication, Department of Geography and Anthropology, Louisiana State University, Baton Rouge, LA 70803.



**Figure 8. Ridge 1 Profile, South Sector (Ford and Webb 1956)\***

### Electro-Magnetic (EM) Conductivity

(EM) conductivity data was collected from Grids 1-4 in the area of Ridges 1-2 in the Southwest Sector (Appendix B, Figures B-2a through B-5b and B-7). At Poverty Point, the EM38B was used in a manner that did not optimize its potential for detecting archeological features. The conductivity maps clearly show indications of the ridge and swale complexes, as well as some relatively strong, discrete anomalies. The source of the linear anomalies that in each grid correspond to the fiducial markers, remain unclear. Similarly, the conductivity maps are not presented as continuous tone image maps; this too may diminish the potential for detecting very subtle anomalies.

On balance, the EM38B survey at Poverty Point was well executed, but did not employ a survey design that was optimal for conditions at the site. Successful use of the EM38B at other prehistoric mound sites (Clay 2001) suggest that the instrument does have excellent potential at Poverty Point, given appropriate modifications to the survey design. Further surveys conducted with closer interval spacing using Geoplot software and removal of the fiducial mark, would enhance detection of cultural phenomena are needed at Poverty Point before the reliability of this instrument can be fully evaluated for its use there.

### Ground Penetrating Radar (GPR)

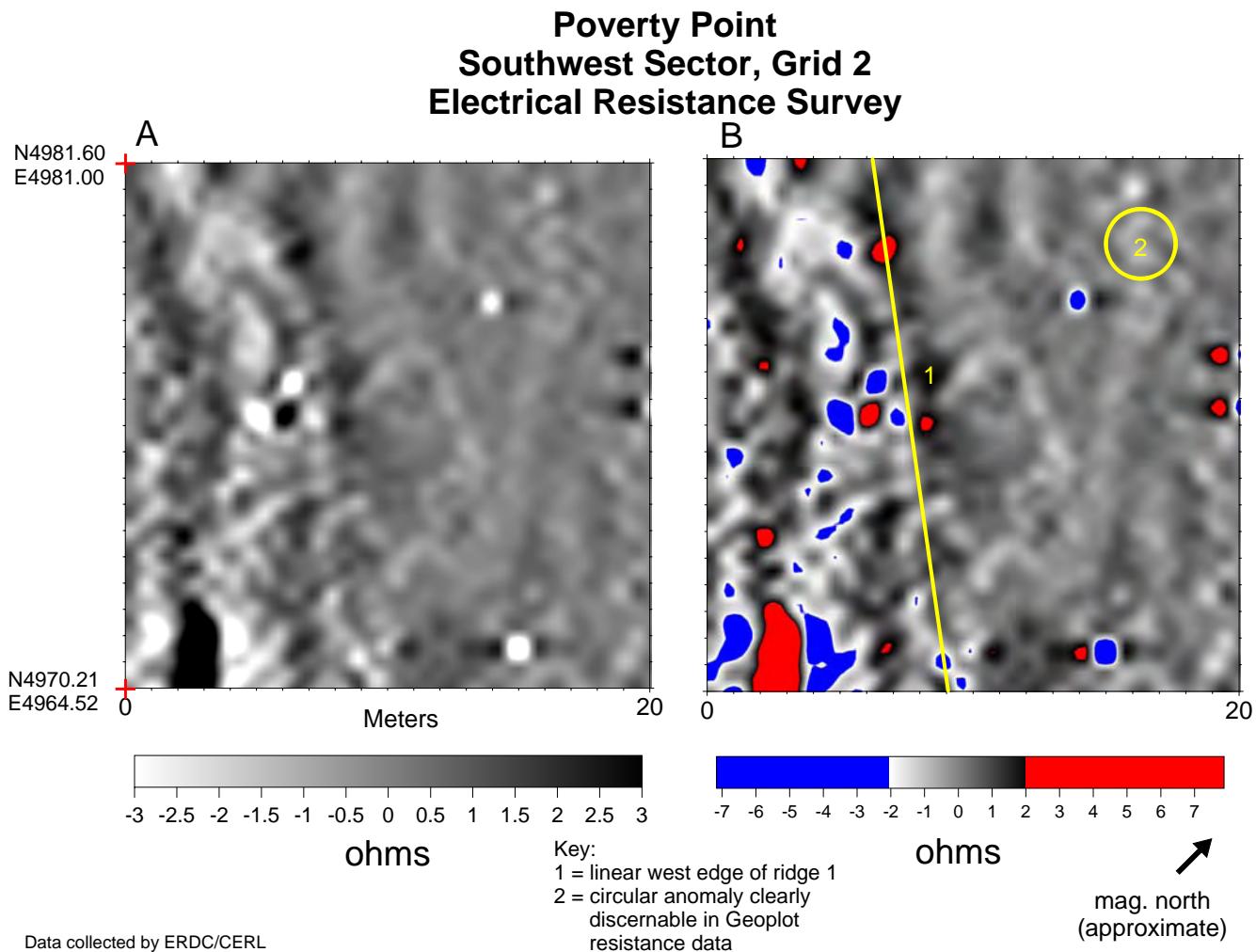
The GPR results collected from Grid 2 (Figure B-6) were generally inconclusive due to the high proportion of clay particles in the loess sediments deposited across the site and along Macon Ridge. The moderately conductive soil, (averaging 15 mS/m), caused the transmitted signal to be attenuated fairly rapidly resulting in a shallow depth of investigation. The GPR data collected using a 250MHz antenna did not reveal any individual anomalies/features. The relatively conductive soil limited the depth of investigation to 70 cm. One anomaly was detected in a disturbed layer within Grid 2 at a depth of 60 cm (Figure B-6) between (0-20E, 0-10N).

\* Reproduced by permission of the Society for American Archaeology from "Poverty Point, A Late Archaic Site in Louisiana" in *American Museum of Natural History, Anthropological Papers* 46 (1) (1956).

## Resistivity Data

Four 20 x 20 m grids of resistivity data were collected along a transect bisecting Ridges 1 and 2 of the Southwest Sector. However, only the data from Grid 2 provided useful results—the one situated atop Ridge 1, Southwest Sector—and is presented here (Figure 9 A and B). The problems that affected the datasets can either be attributed to user error and/or equipment failure. Nevertheless, the one dataset did reveal useful information and indicates promise for this technology at certain locations across the site. Recommendations for future applications are outlined below.

Figure 9, A and B depict image maps of the resistance data collected from the 0.5 m probes (+/- 20-80 cm below surface). Note the defined western edge of Ridge 1 that bisects the image along the left side. Also, notice the small semi-circular feature in upper right-hand corner of the grid. This small semi-circular feature (1-3 m diameter) is characterized by a high resistance border contrasting and enclosing a low resistance interior and extends approximately 1 m below ground surface. This anomaly may represent a storage pit or some sort of material processing feature, or possibly the remnants of a large tree root mold.



**Figure 9. Resistivity Dataset from Grid 2, Ridge 1, Southwest Sector**

## Gradiometer Data

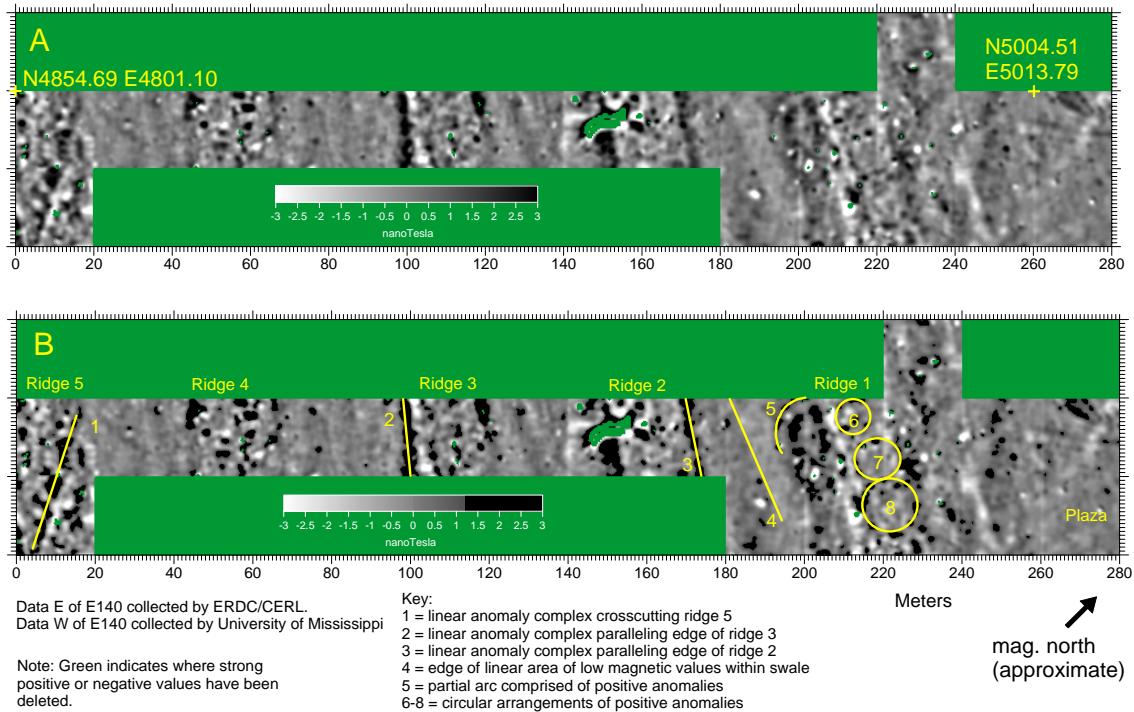
This data set is by far the most revealing, in part because we were able to examine a much larger portion of the site (Figure 10), but primarily because the data show a wider range of anomalies and stronger spatial and recognizable patterning. In the images presented here (Figure 10 A and B), the positive magnetic values are depicted as black, the low negative values as white, and the mean (near zero) are mid-range gray. Notice the banding across the image from top to bottom at regular intervals. These are the subsurface expressions of the ridges and swales, which are remnant architectural features. Topographically, Figure 11 depicts the exact correlation of the geophysical data and the 10-centimeter contour intervals produced using the digital topographic data provided by Louisiana's Division of Archaeology (2000). The combination of accurate surface and subsurface provenience data of cultural phenomena, and the resultant images, have obvious benefits for this and future research.

The gradiometer results as depicted in the above and below comparisons in Figure 10 A and B clearly illustrate the findings and facilitate interpretations. The linear, dark anomaly seen in Ridge 5 is interesting (Figure 10 B, 1). Here the dark band has an orientation distinct from that of the ridge. In fact, the band appears to cross-cut the ridge at an oblique angle. It may be that this orientation is a localized phenomenon. Further gradiometer survey work is needed to provide a more reliable view of this area. The remainder of Ridge 5 (and 6) was not surveyed because of the encroaching treeline.

The gradiometer survey allowed us to observe some general comparisons and dimensions regarding the ridges and swales:

- Ridges 2, 3, and 4 are uniform in width, all being 20 m wide.
- Ridges 1 thru 5 are evenly spaced, being 25 m between outer ridge edges.
- Ridge 1 is much wider, measuring 35 m in width.

**Poverty Point  
Southwest Sector  
Magnetic Field Gradient Survey**



**Figure 10. Gradiometer Datasets Southwest Sector, Ridges 1-5**



**Figure 11. Gradiometer Datasets, Ridges 1-5, Southwest Sector with 0.1 m Contour Overlay**

The ordered architectural/functional configurations indicate that the site layout was planned prior to construction. Furthermore, these dimensions redefine more precisely earlier site descriptions and spatial order in this area (Gibson 2000). Gibson (2000) used different reference points to measure the ridges and swales—the center of the top of the ridge. He also stated there is greater variability between ridge and swale widths. The geophysical methods produced a more accurate and empirical description.

The consistent spacing between Ridges 1 thru 5 suggests pre-planning and order to the architectural arrangement in the areas surveyed. While this is not a new concept at Poverty Point, the precise arrangement of the architecture is new information and indicative of a carefully designed and well-executed plan. Further, it is important to note that the post-occupation damage has not altered the overall remains. What is intriguing is that if the ridgetops were eroded and/or plowed down then, why isn't there greater magnetic variability detected in the swales?

The contrasting light and dark tones indicating magnetic variability along the ridge flanks (see Figure 10 B, 2 and 3) is suggestive that different soils with different properties were used purposely to construct and support the ridges—possibly clay balks along the outside edges of the ridges to retain the loess fill material in the interior. This construction technique, as mentioned earlier, has been documented by Gibson (2000) elsewhere on the site. Actually, what we may be observing is the compressed midden material rather than the clay balk. Magnetic susceptibility analysis of these soil types should be conducted at these locations to confirm this explanation.

Situated on top of the ridges are many discrete anomalies that occur between the long dark bands, which mark the ridge edges. Some of these could represent pits, hearths, and clusters of poverty point objects or other deposits associated with ridge-top activities. The discrete features atop these ridges, some of which form circular patterns, are most intriguing.

Many of these small, irregular anomalies may simply be discontinuous lenses of midden as observed earlier in the Webb and Ford profile (see Figure 10 A and B). It is important to remember that the gradiometer map is a palimpsest of deposits that occur at various depths. The data that we see here pertains to the upper meter or so. Since the ridges have been heavily eroded in this portion of the site, it is likely that the gradiometer map is comprised primarily of the earlier deposits that were, at one point, deeply buried by later portions of the ridges.

The swales are equally perplexing. Magnetically their signature is characterized by relatively quiet, “low” readings, virtually absent of anomalies except for the subtle linear feature between Ridges 1 and 2 (Figure 10 B, 4). The low magnetic variability in the swales indicates that these areas were kept “clean.” However, excavations within the swale areas are not free of artifacts (personal communication, Robert Connolly, 1 March 2002). This phenomenon begs the question: What happens magnetically to the culturally enriched material as it is eroded away?

Beyond the ridge and swale areas toward the central portion of the site we were able to survey 3 grids. These grids are located at the interface of Ridge 1 and the central Plaza (Figure 10). Here, the results depict a scattering of small dark, positive, anomalies. These are generally less than a meter in diameter. Some of these anomalies are weak dipoles, but none have the amplitude suggestive of metal. A number of these small anomalies on the margins of the plaza are reasonable candidates to be associated with hearths, pit features, and/or concentrations of burned material including rock or poverty point objects. The interface where Ridge 1 joins the Plaza should be an area of considerable interest for future geophysical surveys; especially regarding non-domestic activities.

The most intriguing findings occur on Ridge 1. Ridge 1 is unique because it is much wider (35 m—almost twice as wide as the rest), better preserved, and is located adjacent to the main plaza area of the site. Culturally, the combination of these factors suggests that Ridge 1 and the activities that took place there were more prominent than the other ridges.

By far the most exciting anomalies that we detected are the three ringed patterns located atop Ridge 1 that measure approximately 10, 12 and 15 m in diameter (see Figure 10 B, 6, 7, and 8). These appear symmetrical in shape and are positioned across the top of the ridge in a continuous and aligned pattern along the western edge of Ridge 1. The anomalies that comprise the ringed, or circular, patterns are composed of non-contiguous, elongated and curvilinear magnetic highs.

Are these magnetic patterns suggestive of midden deposits, or could they be the remains of a trenched foundation or, of paired-post structures? If these are remnants of structures, why were they built in this manner? If not structures, then what type of localized activity, or by-product, would have left these circular patterns? These magnetic patterns are prime candidates for ground truthing because they may have the potential to definitively address the function(s) and use(s) of Ridge 1 and yield new information leading to a more complete understanding of the behavior and/or practices in the Southwest Sector at Poverty Point.

Immediately to the left of the three circular features on the image, one sees a larger arc extending beyond the ridge limits (Figure 10 B, 5). These are not as symmetrical as the possible circles and remain undefined at this point. We were unable to survey the adjacent grid to the north to investigate the arcs' extent because of a large, metal-wire “wigwam” interpretive display in that area. Are these remnants of pre-ridge occupation?

## **RECOMMENDATIONS**

This pilot study demonstrates the utility of gradiometry and to a lesser degree resistivity techniques at certain locations within the Poverty Point site. Further surveys are needed to resolve the applicability of EM conductivity. The instrument may yet prove useful, as it has at many other sites, when an appropriate survey design is employed—one that is more tightly gridded with closer transects with denser data collection—that is focused on small cultural phenomena.

The GPR has very limited applications at Poverty Point at this time due to the clayey soils and limits of the technology to penetrate these fine particles. Perhaps Ultra-wide band GPR technology will prove useful.

The user/equipment error for the resistivity survey results for the Ridges 1-5 transect, Southwest Sector, can be addressed by re-implementing the original research design but by incorporating recommended solutions offered by Geoscan. They suggest that the resistance meter be reconfigured with a single, twin probe array (and by not running the signal through the Multiplexer), and/or replacing the instrument frame with a new frame, thereby negating the possibility for an electrical current “leak” through the frame, resulting in striped data. A survey is planned to re-collect the data from Grids 1-4.

## *GROUND TRUTHING OF ANOMALIES*

A well designed and executed research design that would target a selected sample of the larger anomalies to determine their true nature would be prudent. The first task in ground truthing is to determine the differences in deposit/feature context of the areas depicted on the gradiometer image maps. This can be done by excavating a test trench that would bisect the contrasting deposits. Ideally, these would be readily discernable and could corroborate our findings and offer insight into the architectural and construction techniques in the areas surveyed.

Once we learn more about what types of anomalies and feature types are detectable with the geophysical instruments and how the anomalies are manifested—via ground truthing and the true nature thereof—then it may be more appropriate to excavate the geophysical targets that may be equally, if not more informative with respect to the Poverty Point culture.

We suggest that a series of closely spaced soil cores be placed across either Ridge 2, 3, or 4 where there appears to be a sharp division of subsurface materials. A Giddings soil sampler extrusion rig would have sufficient diameter to recover an appropriate sample for analysis. A soil scientist should describe the soils, and then the sediments should be processed through graduated screens to recover artifacts as well as floral and faunal materials. Samples of soil strata should be collected and submitted for magnetic susceptibility analysis. This would provide much needed insight into the materials and soil types that we detected in the magnetic data.

## *CONCLUSION*

This study marks a new era of investigation for Poverty Point. The multi-instrument geophysical survey at Poverty Point has revealed new information that not only supports existing models of site formation processes and architecture, but also indicates intriguing activity patterns that have not been previously detected. While further surveys are needed to generate more robust models regarding behavior and function at Poverty Point, an informative methodological approach has been established demonstrating the effectiveness and efficiency of employing geophysical survey.

Several targets have been identified for ground truthing that could address the research questions offered above. Ultimately, the information recovered from the excavations, when compared with the geophysical data, will allow for refinements to be made to future geophysical survey designs and allow more precise applications of these technologies at Poverty Point.

*Acknowledgments:*

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*This study owes a very special thanks to “Rebel Geophysics” from the University of Mississippi. Jay Johnson, Al Lemmon, Matt Reynolds, Brian Haley, and John Peukert did an exceptional job of collecting geophysical data as well as surveying in our grid coordinates (almost) and sharing their Geoplot knowledge. Their efforts contributed significantly to the success of this study. Thanks Guys!*

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## APPENDIX A: SOUTHWEST SECTOR, RIDGES 1-5 SURVEY AREA

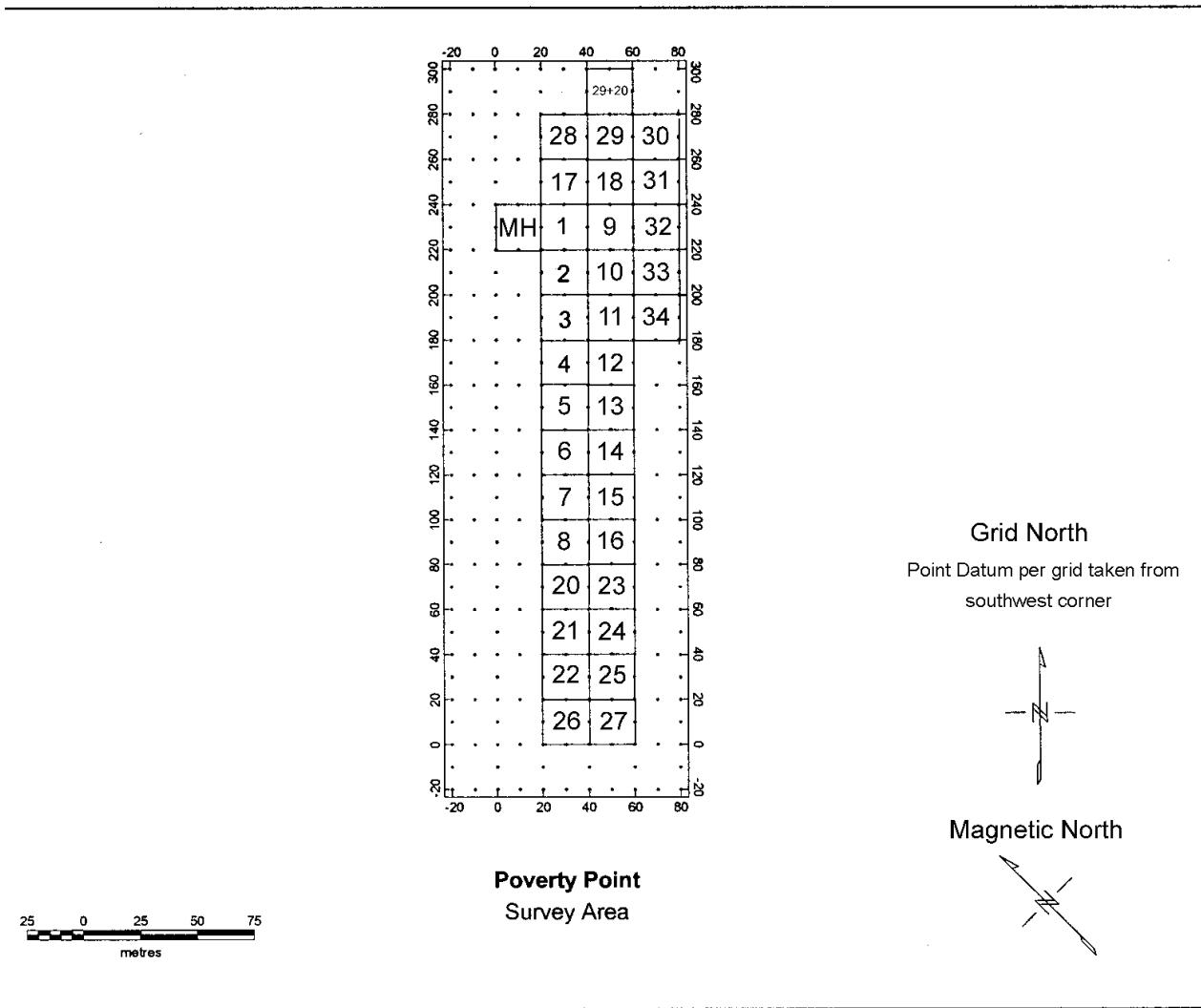


Figure A- 1. Poverty Point, Southwest Sector, Ridges 1-5 survey area.

**Table A-1. SOUTHWEST SECTOR, RIDGES 1-5 SURVEY  
AREA, DATUM/GRID UTM COORDINATES**

Datum/Grid	Northing	Easting	Elevation (m)
MON 1	4839.864	4999.861	30.712
MON 2	5414.8604	5000.0117	30.514
MON 5	4846.5073	4618.5283	30.675
1	4981.602499	4981.000122	31.276981
2	4970.211439	4964.597687	31.415765
3	4958.807868	4948.18252	31.098672
4	4947.373322	4931.748996	31.103809
5	4935.925585	4915.335093	30.870188
6	4924.327024	4898.792621	30.858872
7	4912.453274	4882.472883	30.979654
8	4900.839889	4866.212808	30.786781
9	4965.234342	4992.448025	31.533992
10	4953.764664	4976.021551	31.256429
11	4942.415506	4959.569971	31.051205
12	4930.960751	4943.144804	31.013747
13	4919.489732	4926.725434	30.74607
14	4907.98727	4910.367168	30.870131
15	4896.290222	4894.156983	30.944365
16	4884.596657	4877.876273	30.743495
17	4993.051988	4997.397354	30.960829
18	4976.663361	5008.839314	31.011092
20	4889.358632	4850.06429	30.987346
21	4877.811604	4833.740225	30.877224
22	4866.261757	4817.412869	30.863937
23	4872.979395	4861.624433	30.987661
24	4861.499178	4845.282718	30.677948
25	4849.973532	4828.900658	30.774272
26	4854.690486	4801.103189	31.330423
28	5004.512539	5013.79387	30.712
29	4988.096688	5025.260296	30.733874
29+20	4999.492717	5041.6214	30.444018
30	4983.128477	5053.06788	30.389699
31	4971.679563	5036.694212	30.705365
32	4960.293446	5020.231937	31.156116
33	4948.712643	5003.962231	31.768208
34	4937.430256	4987.476897	31.138747

Point Datum per grid taken from southwest corner, referenced to grid north

**APPENDIX B:**  
**INITIAL GROUND CONDUCTIVITY AND GPR SURVEY**  
**AT POVERTY POINT STATE COMMEMORATIVE**  
**CENTER (16WC5) WEST CARROLL PARISH, LOUISIANA**

Draft Report

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**INTRODUCTION**

The Poverty Point State Commemorative Site (16WC5) is a Late Archaic prehistoric archeological site located in rural West Carroll Parish, Louisiana. A geophysical survey was conducted to gain a better understanding of the site formation processes, lifeways, trade interactions, and social order at the site. This study is an initial investigation to determine if the noninvasive techniques employed in geophysics are applicable at this site. If so, geophysical surveying will provide a relatively fast and cost effective means for surveying large areas and identifying features for further investigation by archaeologists. The investigation team consisted of personnel from the Engineer Research and Development Center (ERDC) and the University of Mississippi (UM). The ERDC members included archaeologists from the Construction Engineering Research laboratory (CERL) and a geophysicist from the Geotechnical and Structures Laboratory (GSL). The CERL team conducted magnetometer and electrical resistivity surveys. The UM team also performed magnetometer surveys, whereas the GSL researcher used ground conductivity and ground penetrating radar methods.

This report describes the geophysical methods and results pertaining to the surveys conducted by GSL. Two geophysical methods, electromagnetic and ground penetrating radar (GPR), were used to survey several grids. The geophysical surveys were performed 21-22 June 2001. The CERL team acted as the project leaders. The work was not funded but it is hoped that the results will emphasize the benefits of using geophysics at archeological sites, increase knowledge of the site, and lead to future funded studies.

**SURVEY AREA AND GRID LAYOUT**

The geophysical survey encompassed an irregularly shaped area having maximum dimensions 280 m in length and 60 m wide. The area was subdivided into 20 m by 20 m grids for surveying purposes. The survey area was oriented in a northeasterly direction and the ground surface was relatively flat with a few scattered animal burrows. The electromagnetic and GPR surveys reported here were performed over just four (P1-P4) of

the 21 grids (Figure B-1). Ground conductivity data were collected over all four grids, whereas only Grid 2 was profiled using GPR. The north and south boundaries of each grid were flagged using PVC pin flags at 1-m intervals. This was also done along the mid-line of the grid to aid data collection and distance control. The geophysical surveys were conducted along profile lines spaced 0.5 m apart.

## GEOPHYSICAL METHODS

### Electromagnetic

The electro-magnetic (EM) induction method is commonly used to measure apparent ground conductivity. The conductivity of a material is dependent on the degree of water saturation, types of ions in solution, porosity, chemical constituents of the soil, and the physical nature of the soil. Due to these factors, conductivity values can range over several orders of magnitude.

There are two components of the induced magnetic field measured by the EM equipment. The first is the quadrature phase component, sometimes referred to as the out-of-phase or imaginary component, which gives the ground conductivity measurement. Disturbances in the subsurface caused by compaction, soil removal and fill activities, or buried objects may produce conductivity readings different from that of the background values, thus indicating anomalous areas. Electrical conductivity is a positive valued parameter. However, due to the design of the instrument used in this survey to collect conductivity data, it is possible to obtain a negative value when the instrument passes over a metallic object. Although a negative conductivity value is physically meaningless, it does aid in the detection of metallic material. Quadrature readings are reported as milliSiemen/meter (mS/m). The second component is the inphase or real component, which is the ratio of the induced secondary magnetic field to the primary magnetic field. The inphase component is primarily used for calibration purposes; however, it is also sensitive to metallic objects. The inphase component is measured relative to an arbitrarily set level and assigned units of parts per thousand (ppt). Since it has an arbitrary reference level, the reading can be either a positive or negative value.

A Geonics EM38BB terrain conductivity meter was used for this investigation. The EM38BB operates in the frequency domain at 14.6 kHz, has a transmitter-receiver coil separation of 1 m, and a maximum effective depth of investigation of approximately 1.5 m. The instrument can be operated in both a horizontal and vertical dipole orientation, each having different depths of investigation. The instrument is normally operated with the dipoles vertically oriented (coils oriented horizontally and co-planar), which gives the maximum depth of penetration. For this survey the EM38BB was operated in the vertical dipole mode to achieve the maximum depth of investigation.

Data were collected using a 0.6-second sampling interval as the operator walked along profile lines spaced 0.5 m apart. At this pace, the data were acquired at about 3 measurements per meter. Measurements were taken at the ground surface and a fiducial mark placed in the data file at 10 m (mid-grid) to provide distance control.

### **Ground Penetrating Radar**

Ground penetrating radar (GPR) is also an electromagnetic method, however it differs significantly from the induction EM method described above and warrants a separate discussion. At the lower frequencies (kilohertz range) where EM induction instruments operate, conduction currents (currents which flow via electrons in a metallic matrix or ions in solution) dominate and energy diffuses into the ground. At the higher frequencies (megahertz range), which GPR utilizes, displacement currents (currents associated with charges which are constrained from moving any distance) dominate and EM energy propagates into the ground as a wave.

GPR is used to image the subsurface by transmitting an electromagnetic pulse into the earth and measuring the return signal. The frequencies employed in GPR typically range from 10 to 1000 MHz. While in the earth, the EM signal undergoes refraction, reflection, scattering, and dispersion. Contrast in the dielectric permittivity at material boundaries causes the EM wave to be reflected and refracted. Soil conductivity is a major factor in determining if GPR can be used successfully at a site. High conductivity soils, such as those with a high clay and moisture content, can significantly attenuate the EM signal and frequently render GPR virtually useless.

A Sensors & Software, Inc. Noggin system was used to collect the GPR data. The Noggin is noted for its user-friendliness, simplicity, and self-contained data acquisition system. Both the transmitter and receiver antennas are contained in one unit mounted on a cart that is pushed along the surface at a slow walking speed. The GPR survey was performed in reflection mode with the antennas oriented perpendicular to the survey line. In reflection profiling, the transmitter and receiver antennas are kept a fixed distance apart and both antennas are simultaneously moved along the survey line. A wheel odometer attached to the system is used to monitor distance traveled and initiate data sampling at 5-cm increments. The time (in nanoseconds) required for the EM wave to travel through the subsurface and return to the receiver is recorded at each sample station. The GPR profile is constructed by plotting the received signal against two-way travel time at each sample station along the survey line. A 1000 MHz antenna was initially used the first day of surveying in hopes of acquiring high-resolution near-surface images. However, the local soil conditions did not allow sufficient penetration of the signal (about 25 cm) so a 250 MHz antenna was used the following day. Only the data acquired over Grid 2 using the 250 MHz antenna is presented here. The GPR profiles were also conducted along survey lines spaced 0.5 m apart.

## GEOPHYSICAL RESULTS

### Electromagnetic

The EM38BB electromagnetic survey yielded plots of ground conductivity and inphase measurements. Often a detected anomaly is observed on both plots but one component may see an anomaly that the other component does not. The inphase component generally indicates the location of metallic objects, both ferrous and non-ferrous. When referring to grid locations on the data plots discussed below, east represents the positive x-direction and north the positive y-direction.

#### *Grid 1*

The background conductivity (Figure B-2a) varies between 15-19 mS/m and increases from the top of the grid to the bottom, northeast to southwest. The conductivity only varies 13.2 mS/m over the entire grid, having a maximum value of 22.7 mS/m and minimum 9.5 mS/m. The background inphase measurements vary about 0.3 ppt with a total variation over the entire grid of less than 1 ppt (Figure B-2b). Although the variations in conductivity and inphase measurements are small, the data tend to suggest a weak linear anomaly across the center of the grid (0-20E, 9-11N). There may also be a linear feature that extends from (4.5E, 0N) to (4.5E, 8N). The soil in the lower left corner of the grid (0-7E, 0-2N) exhibits the highest conductivity values.

#### *Grid 2*

The higher background conductivities observed in the southern half of P1 continue into the northern section of Grid 2, having values 14-18 mS/m. The southern portion of Grid 2 has a lower background conductivity of 7.5-12.5 mS/m (Figure B-3a). The range of variation in conductivity over the entire grid is 20.7 mS/m. There is a small point source anomaly located at (6E, 7N). The background inphase data vary about 0.5 ppt with a total variation of only 1.8 ppt (Figure B-3b). Again, the data suggest a weak anomaly across the center of the grid (0-20E, 9-11N). The inphase plot also indicates a possible linear anomaly in the lower half from (0E, 4N) to (15E, 10N). This feature appears to correlate with a linear magnetic trend.

#### *Grid 3*

The overall conductivity variation across this grid is 22.6 mS/m with the background between 10-12 mS/m (Figure B-4a). The inphase variation is quite similar to Grid 2, having a background variation of 0.5 ppt and a total variation of 1.7 ppt (Figure B-4b). There is a conductivity anomaly low at (4.5E, 8.75-10N) with a corresponding weak inphase anomaly high. There is also an anomaly low in the inphase data at (18.5E, 10N). Since the inphase responses are not strong, the anomalies probably are not caused by a piece of metal, but more likely a geologic feature, such as a pocket of gravel, or caused by human activity. Although the conductivity and inphase values do not vary much, there appears to be a linear trend across the center of the grid (0-20E, 9-11N).

#### *Grid 4*

As observed in the other grid data plots, the range of variation in the conductivity (13.5 mS/m) and inphase (1.3 ppt) measurements is also small over Grid 4. The background conductivity is 12-15 mS/m while the inphase background varies about 0.5 ppt. Both the conductivity (Figure B-5a) and inphase (Figure B-5b) plots suggest a weak linear anomaly across the center of the grid (0-20E, 9-11N).

*Comment added by CERL researchers: The Figures B-2 though B-5 and B7 all depict a linear anomaly bisecting each grid at the 10 m transect interval station. Because a fiducial mark was manually inserted into the dataset by the EM operator at this point, the correlation between the two indicates that the linear feature is an operator introduced anomaly and not reflective of a geophysical signature.*

#### **Ground Penetrating Radar**

Minimum depth of investigation using the 250 MHz antenna is about 25 cm, whereas maximum depth achieved at this site is about 70 cm. The soil in this area did not provide a very good environment for a GPR investigation. The moderately conductive soil, average 15 mS/m, caused the transmitted signal to be attenuated fairly rapidly resulting in a shallow depth of investigation. Combined with a quarter-meter resolution, only larger features could be imaged.

#### *Grid 2*

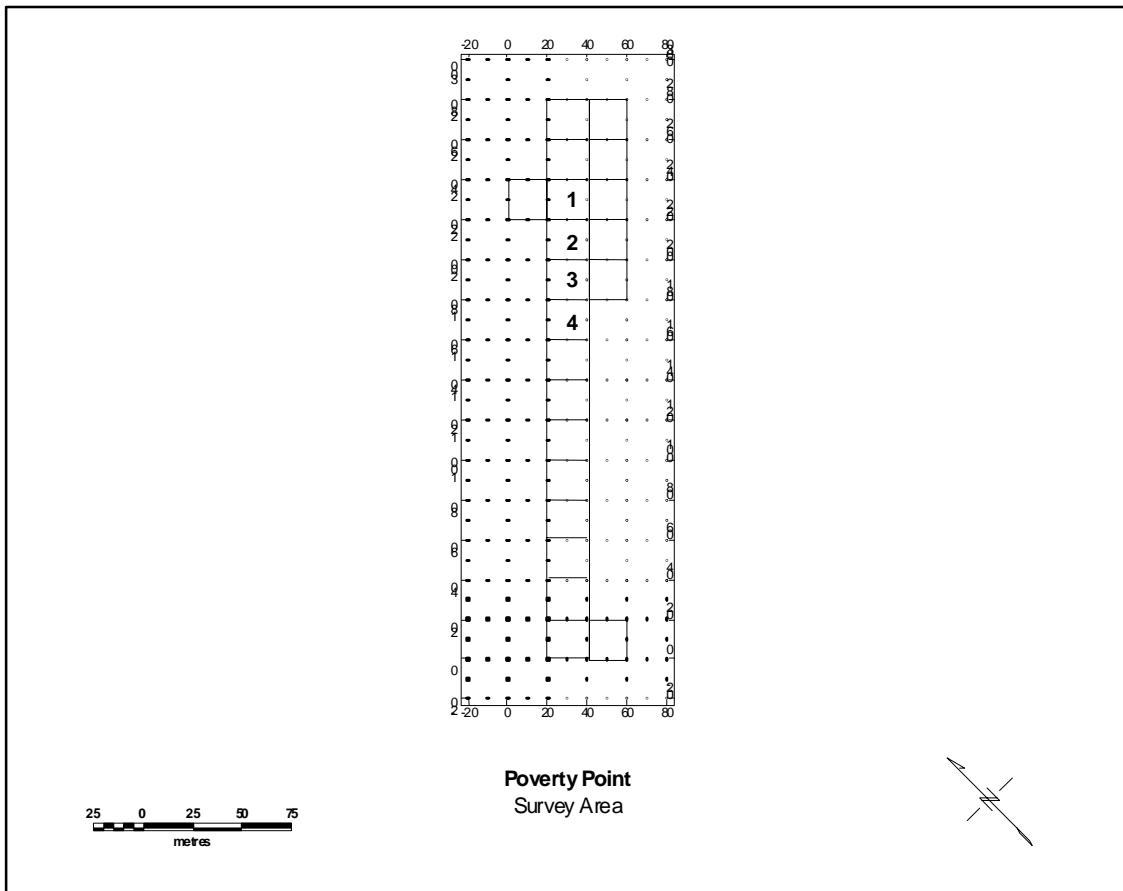
A continuous subsurface soil layer is present at a depth of about 37 cm. Below this layer is a highly disturbed surface at about 60 cm depth. This reflector is relatively continuous across the grid from (0-20E, 0-10N) and shows intermittent reflections between (0-16E, 10-20N). Beyond 16 m east greater continuity of the reflector is observed between 10 to 20 north. The locations of the more prominent disturbances along this reflector are listed in Table B-1. Figure B-6 shows a typical radar profile collected over this grid.

<b>Table B-1. Location within Grid 2 of most prominent disturbances along 60-cm reflector</b>	
X (East), m	Y (North), m
2.5	6
4	7
6.5	5
7.5	5.5
8	6
8.5	5.5
15.5	4
15.5	5
16	4.5
16	7.5
16.5	3
18	5.5
20	9.5
20	11

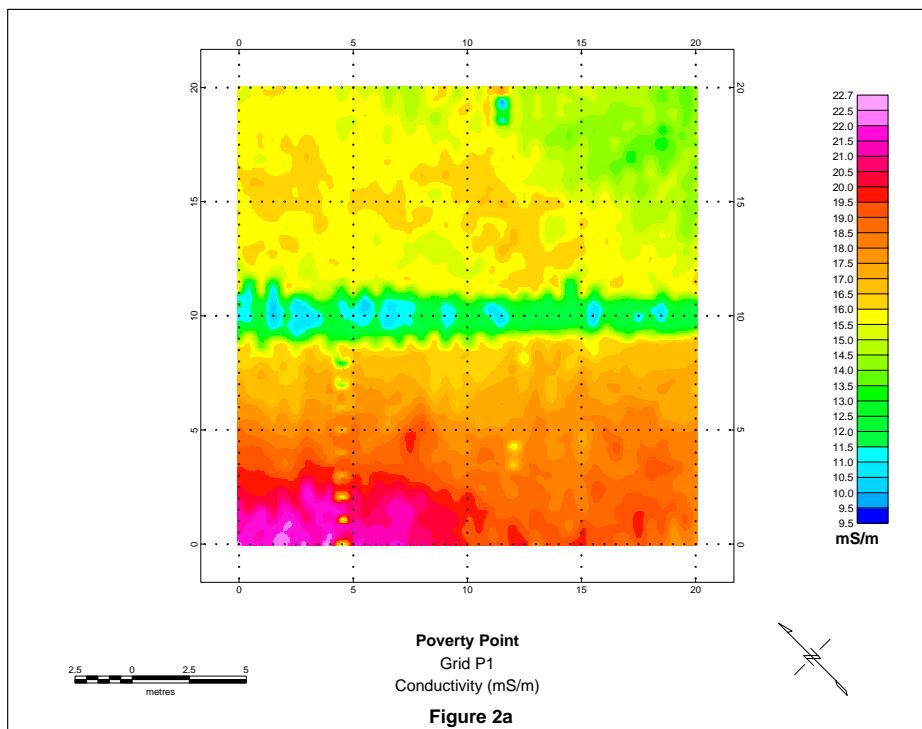
## Summary

The conductivity and inphase data acquired over the four grids exhibit a weak anomaly across the center of each grid. Figure B-7 is a composite of the conductivity data and a difference in values across east-west lines 10N, 30N, 50N, and 70N is apparent. These linear anomalies are weak and may represent a geologic change in soil type or soil properties. However, since the anomalies are regularly spaced, they may be an artifact of human activity and represent a feature where the subsurface soil has undergone greater compaction, such as a pathway. In addition to these anomalies, the inphase data over Grid 2 (Figure B-3b) suggests a linear anomaly from (0E, 4N) to (15E, 10N) that tends to correlate with a magnetic linear trend.

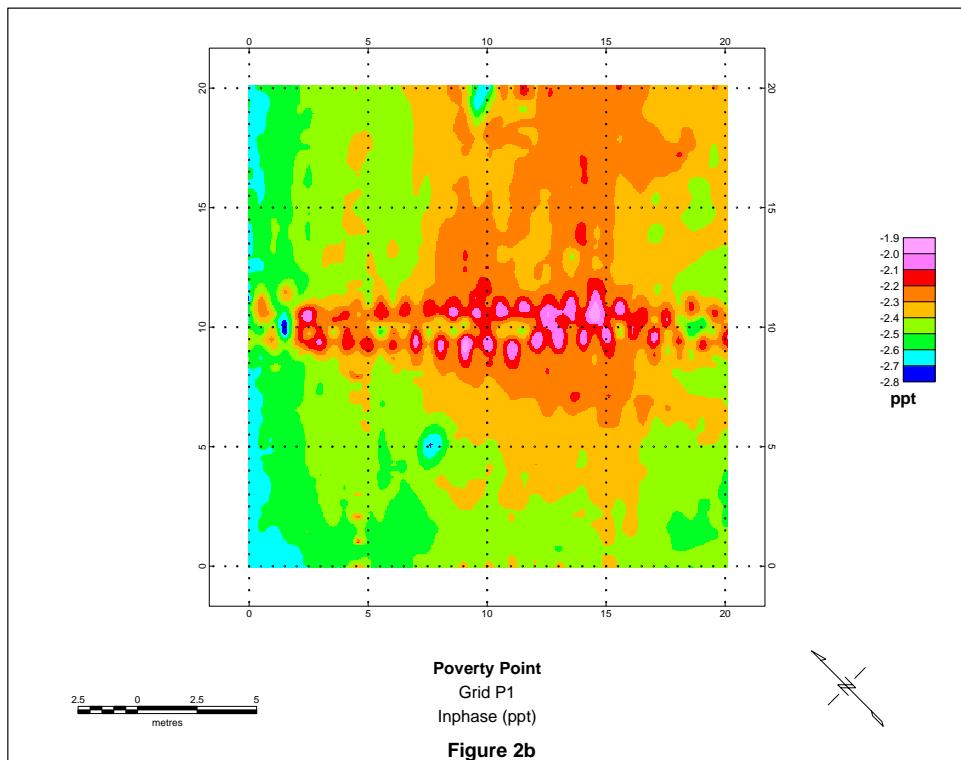
The GPR data collected using a 250MHz antenna did not reveal any individual features. The relatively conductive soil limited the depth of investigation to 70 cm. A disturbed layer was noted in Grid2 at a depth of 60 cm between (0-20E, 0-10N). It is questionable whether a 500 MHz antenna would provide more information. The resolution is better but the depth of investigation is shallower and it is doubtful if much useful information could be acquired below the plow zone.



**Figure B-1. Southwest Sector Survey Grids**



**Figure B-2a. Grid P1, Conductivity (mS/m)**



**Figure B-2b. Grid P1, Inphase (ppt)**

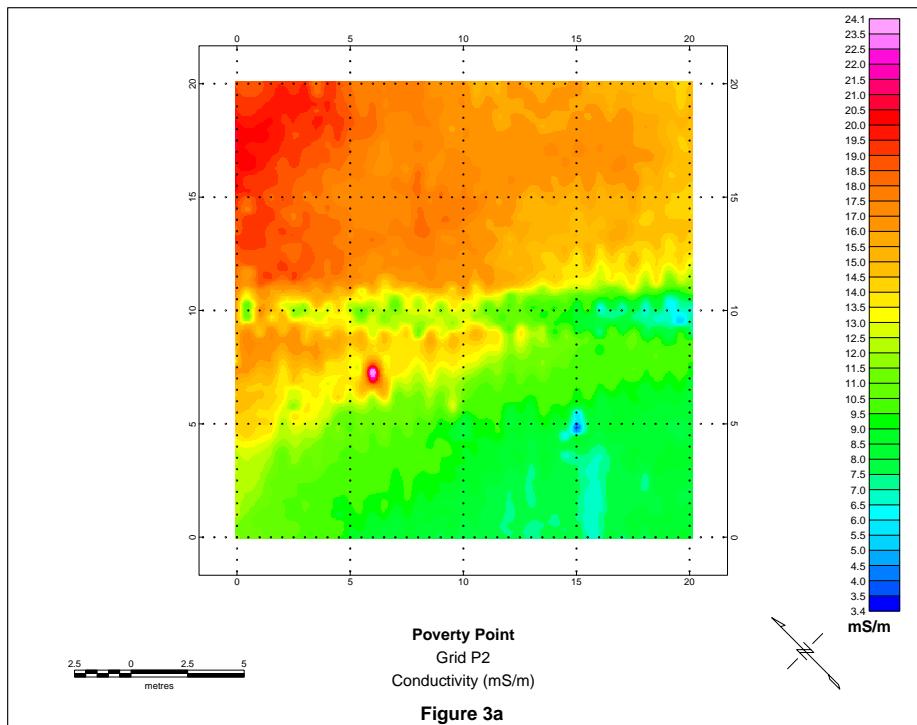


Figure 3a

**Figure B-3a. Grid P2, Conductivity (mS/m)**

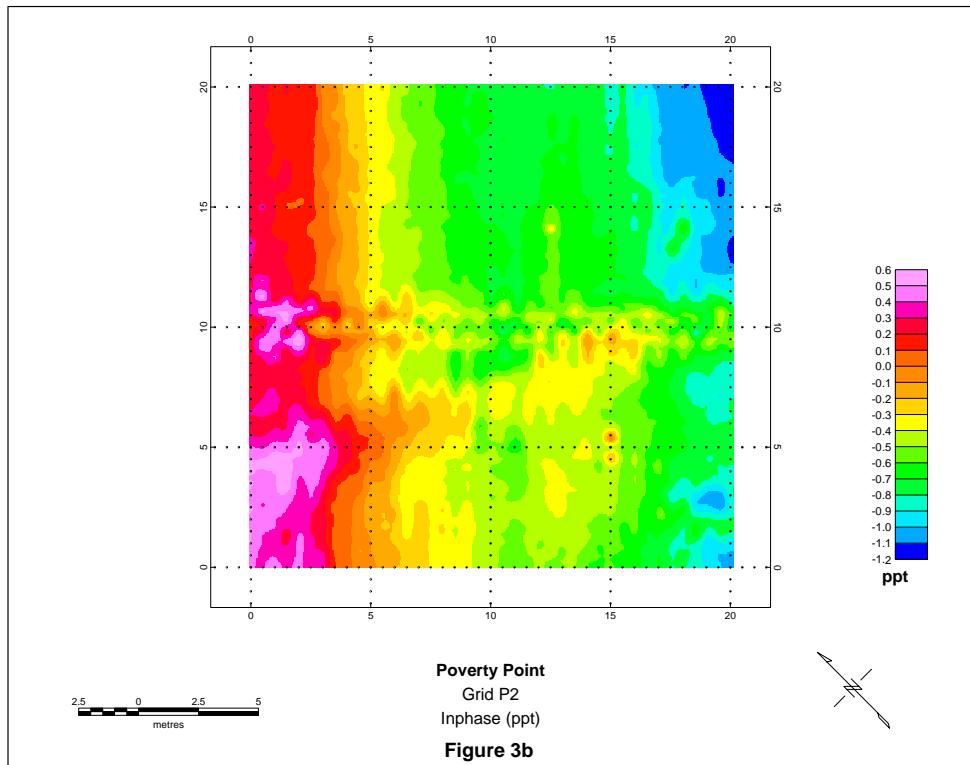
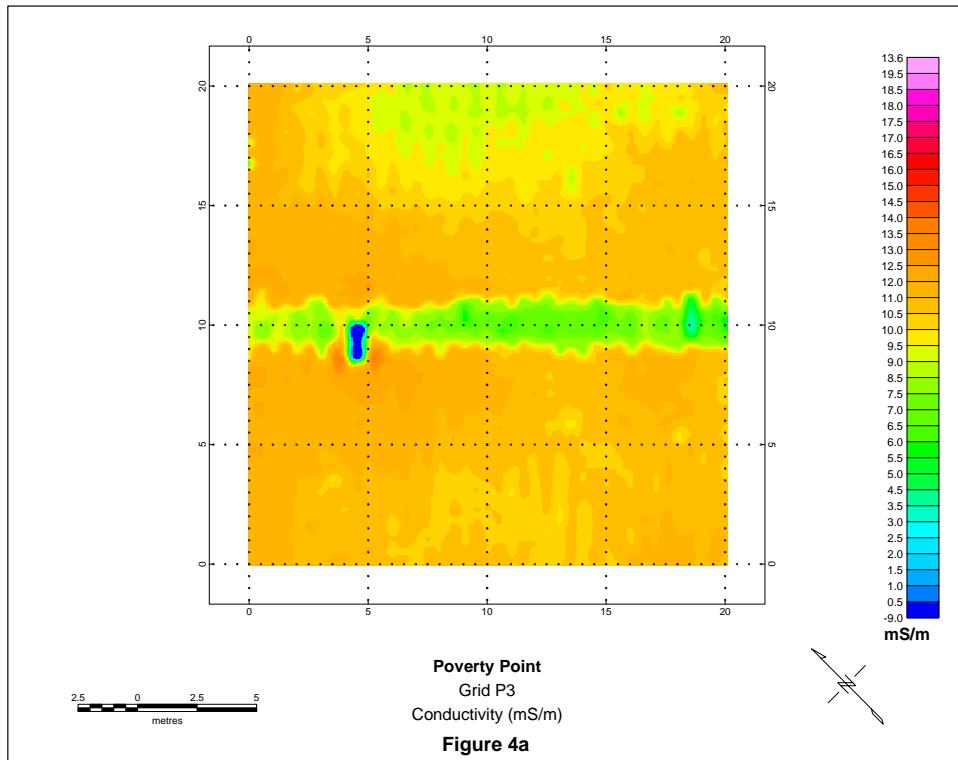
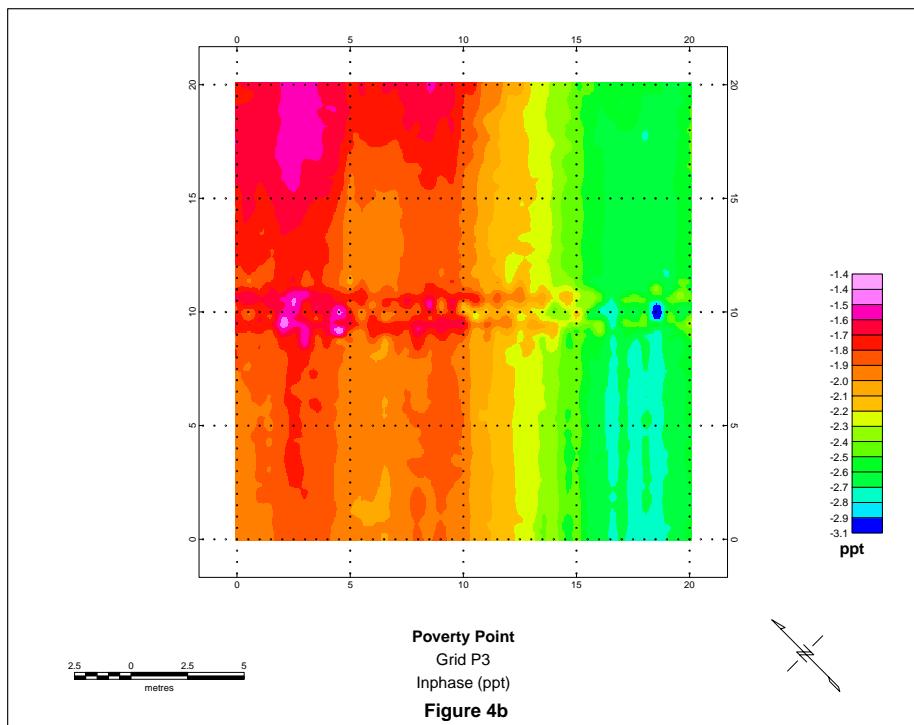


Figure 3b

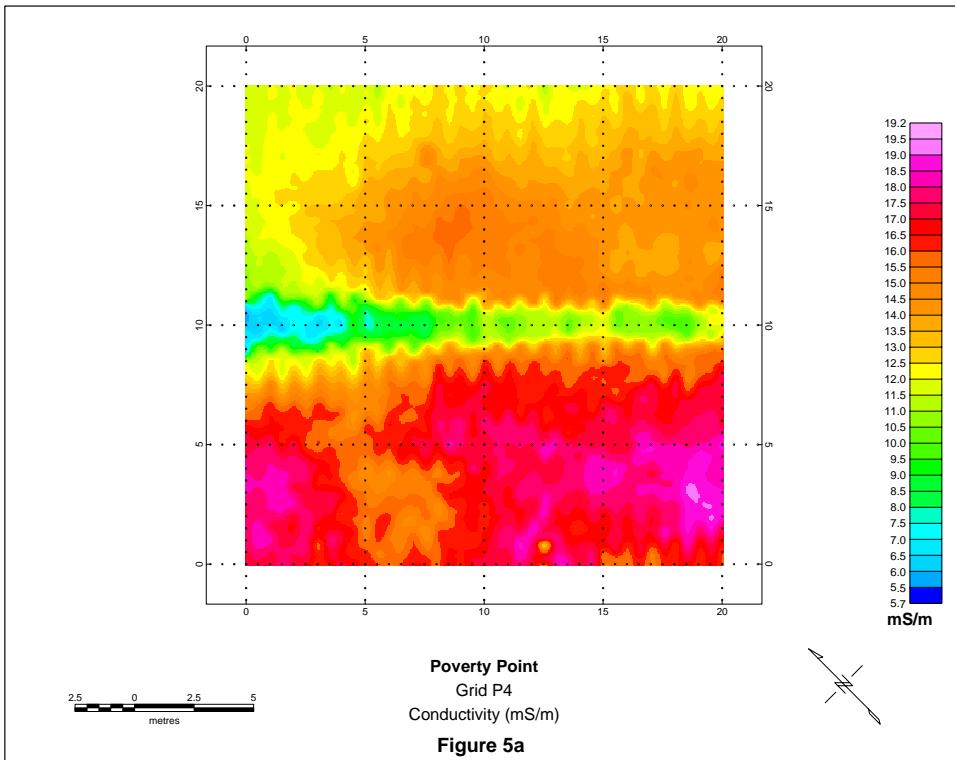
**Figure B-3b. Grid P2, Inphase (ppt)**



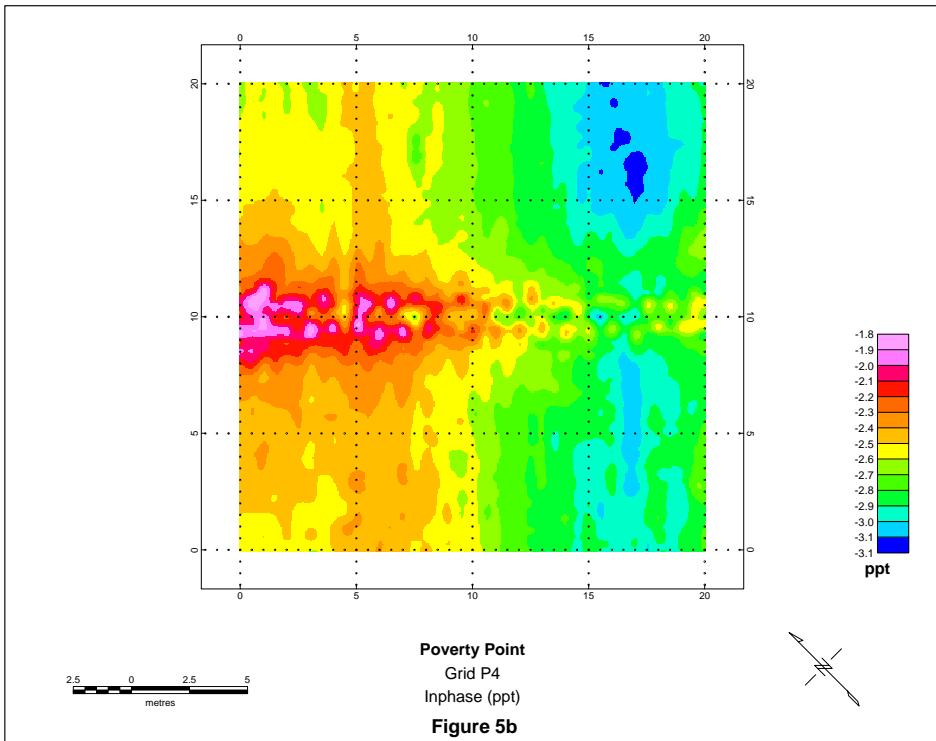
**Figure B-4a. Grid P3, Conductivity (mS/m)**



**Figure B-4b: Grid P3, Inphase (ppt)**



**Figure B-5a. Grid P4, Conductivity (mS/m)**



**Figure B-5b. Grid P4, Inphase (ppt)**

Grid P2, GPR Profile 4 m East

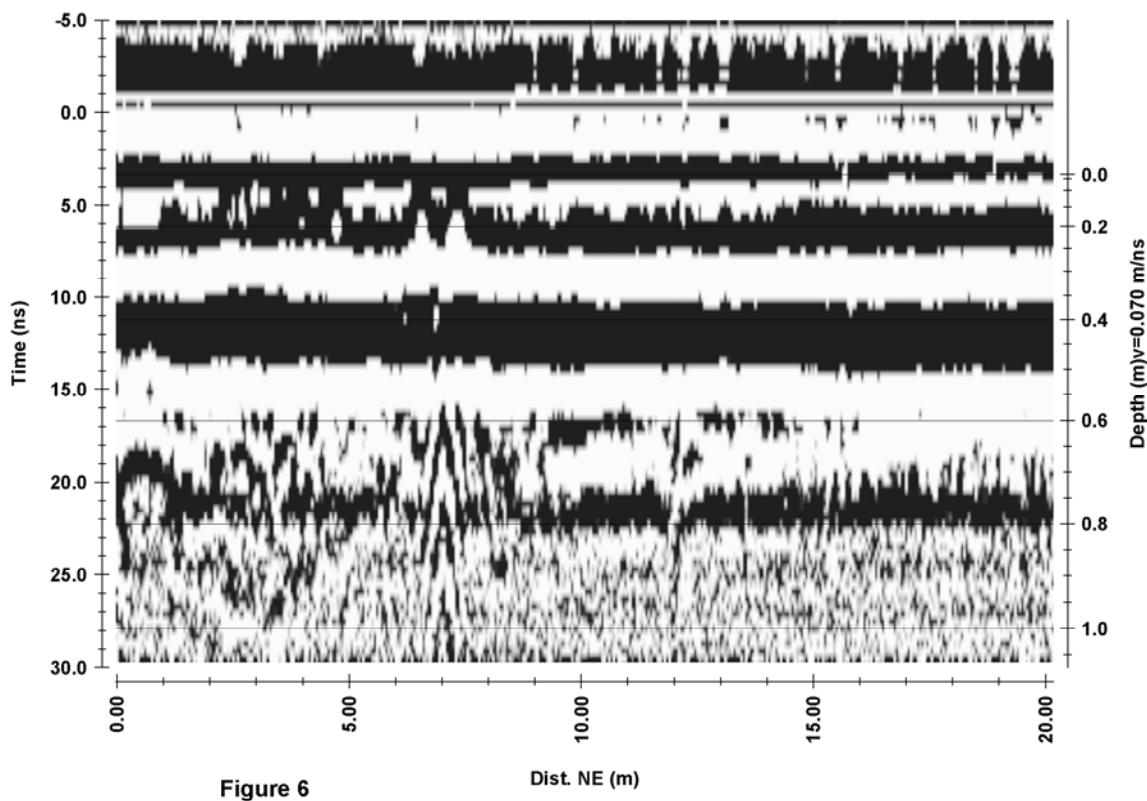
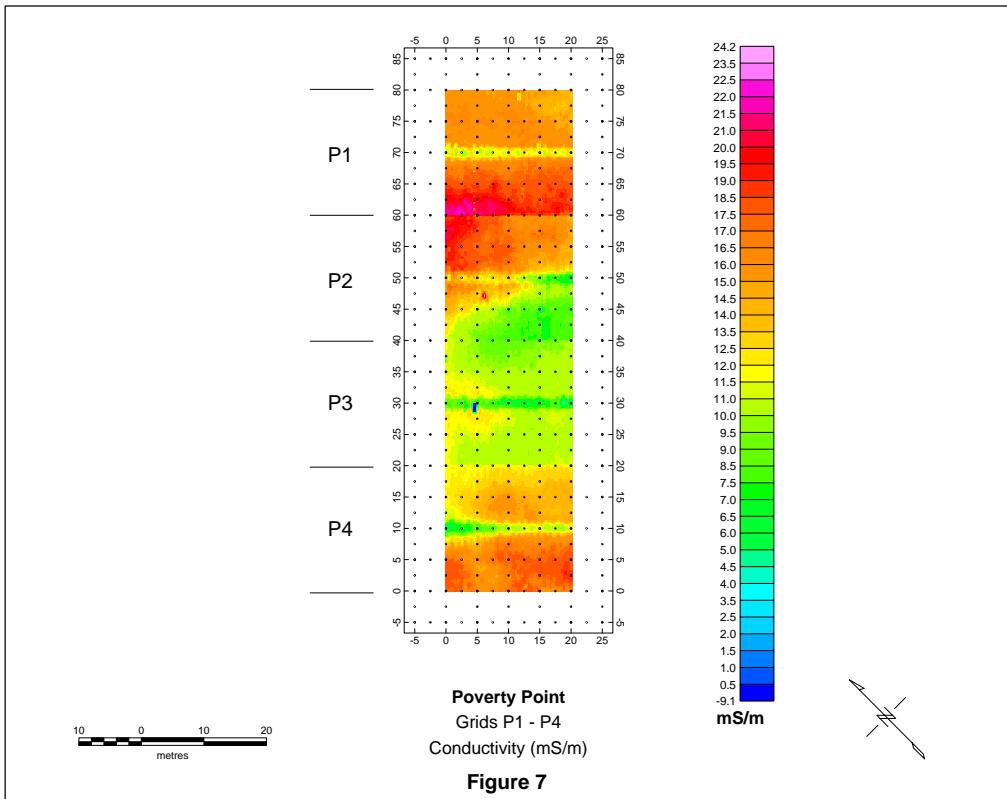


Figure 6

Dist. NE (m)

**Figure B-6. A typical radar profile**



**Figure B-7. Grids P1-P4, Conductivity (mS/m)**

